INTRODUCTION

TO

SYSTEMS ENGINEERING

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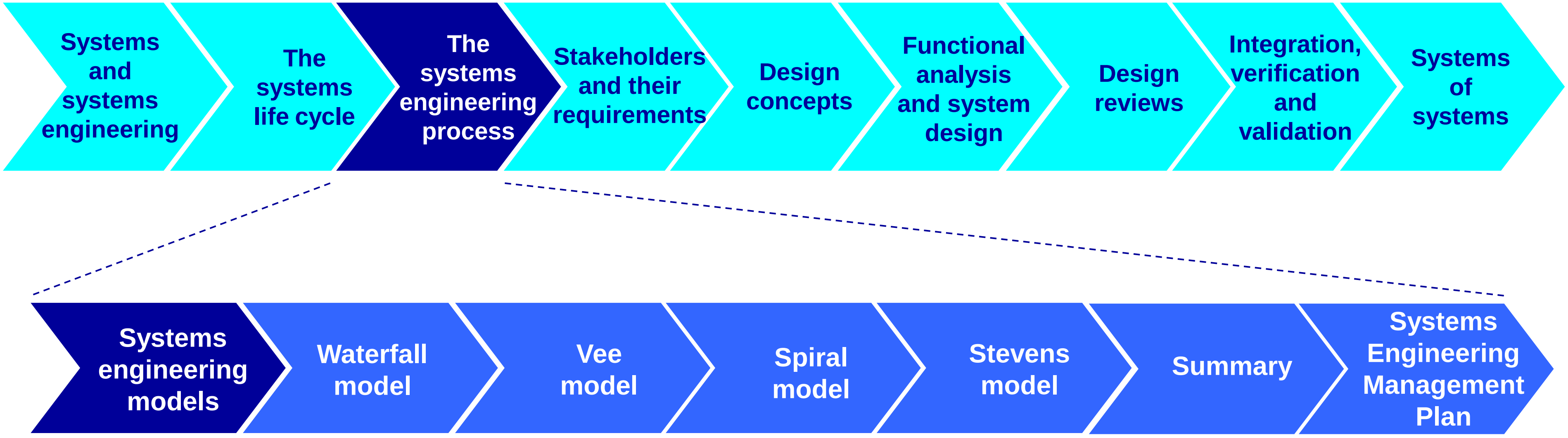
Systems and systems engineering
The systems life cycle
The systems engineering process
Stakeholders and their requirements
Design concepts
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Design reviews
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Systems of systems
Systems engineering models
Waterfall model
Vee model
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Summary
Systems Engineering Management Plan

All roads lead to Rome

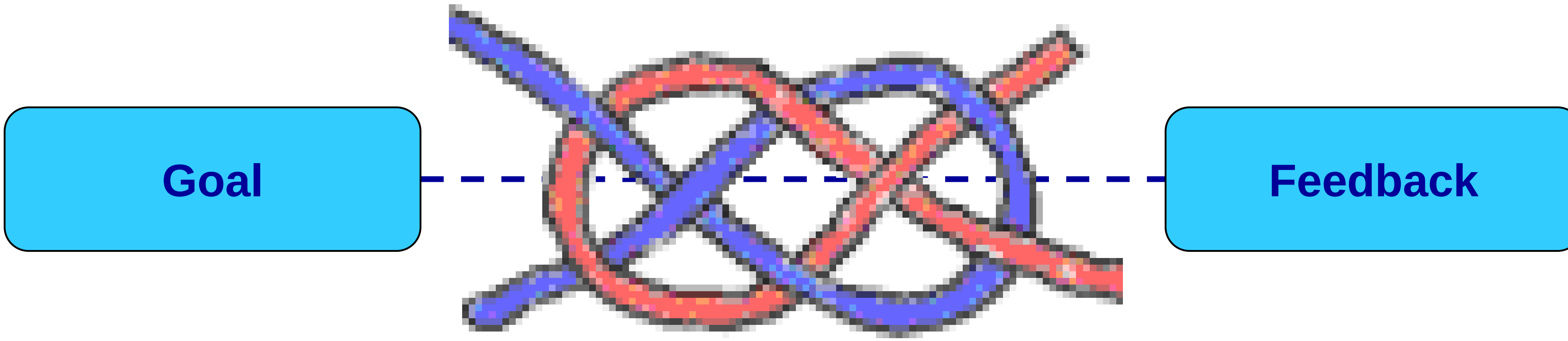
- **As the saying goes, *all roads lead to Rome*, and in fact they once did. The road system of the ancient Romans was one of the greatest engineering accomplishments of its time, with over 50,000 miles of paved road radiating from their center at the Miliarius Aurem in Rome (from which all distances were measured).**

- **Similarly, there is more than one way from getting to the perceived need or opportunity to the system that will fulfill it.**

All roads lead to Rome

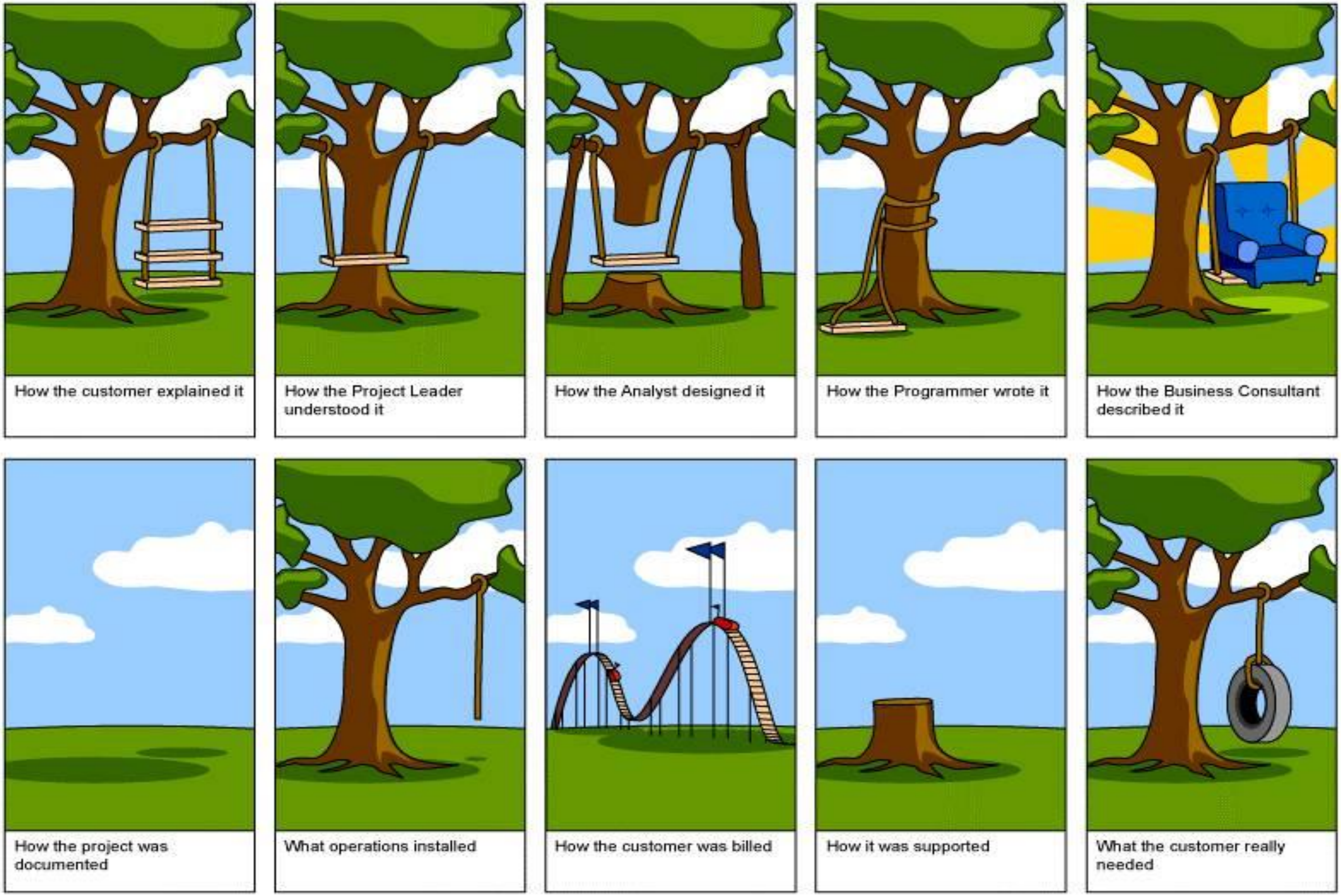
- Given several alternative courses of action, each one will entail its own pros and cons (in terms of effectiveness, efficiency, risk, and the like).
- Each of the systems engineering methods can potentially deliver the desired results (the design of the required system).
- The systems engineer should know the methods available, their pros and cons, and select the most appropriate one, or even conceive his own!

Goal and feedback



What is important is not to lose sight of the goal sought, and to duly rely on feedback in order to alter the course of action as needed.

The tree swing



Goal and feedback

Identifying and Understanding Problems and Opportunities
?

Understand the needs of the various stakeholders

Goal and feedback

Gender and diversity perspective in systems design?
A reality or utopie ?

Understand the needs of the various stakeholders
Airbag system

Requirements

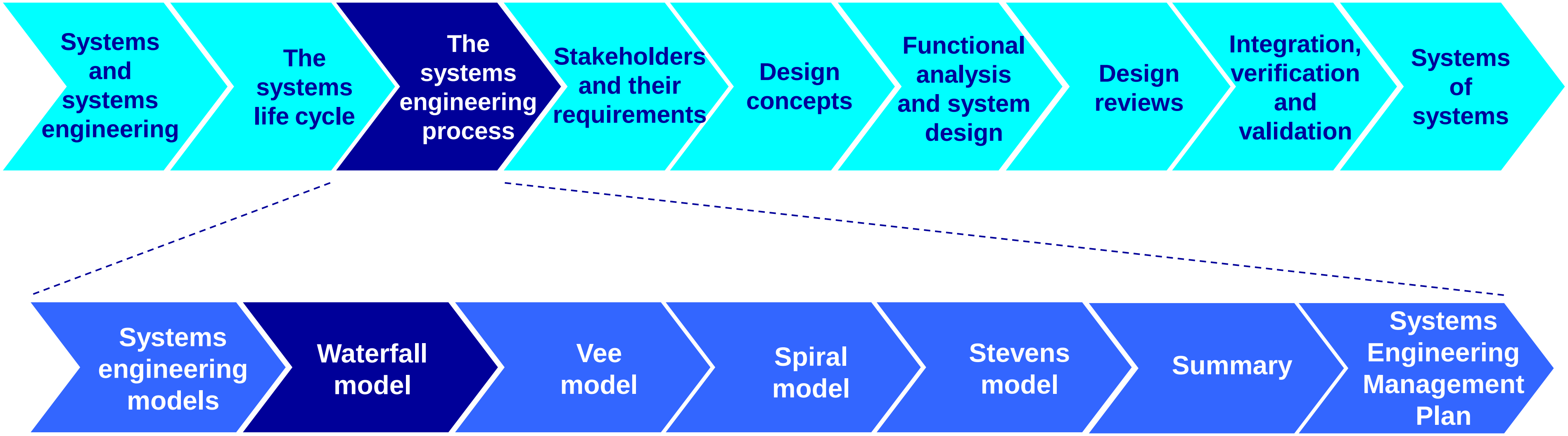
It makes no sense to be exact about something when you do not even know what you are talking about.

(John von Neumann)

Lack of synthesis capability

'My apologies for having written such a long letter; I did not have the time to write a short one'

(Sir Winston Churchill)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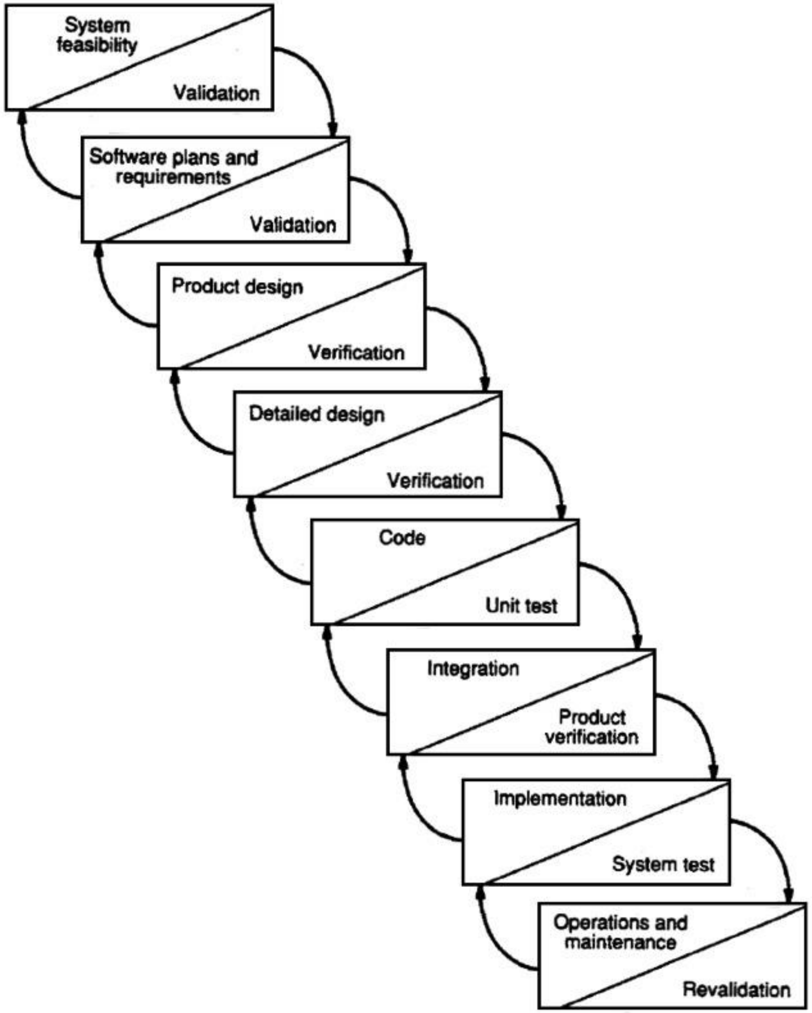
The Waterfall model



- **Dr. Winston Royce published in 1970 the paper 'Managing the development of large software systems'.**
- **He described the model, although did not call it 'waterfall'.**

The Waterfall model

- The Waterfall model originated in the software field but rapidly become widely used.

- The Waterfall model resembles very much the relay race: all steps are carried out in pure sequence.

- On the other hand, it lacks the visibility given by simultaneous consideration of steps, as with the rugby team analogy.

Waterfall (pro)

- Easy to understand, easy to use
- Provides structure to inexperienced staff
- Milestones are well understood
- Sets requirements stability
- Good for management control (plan, staff, track)
- Works well when quality is more important than cost or schedule

Waterfall (Con)

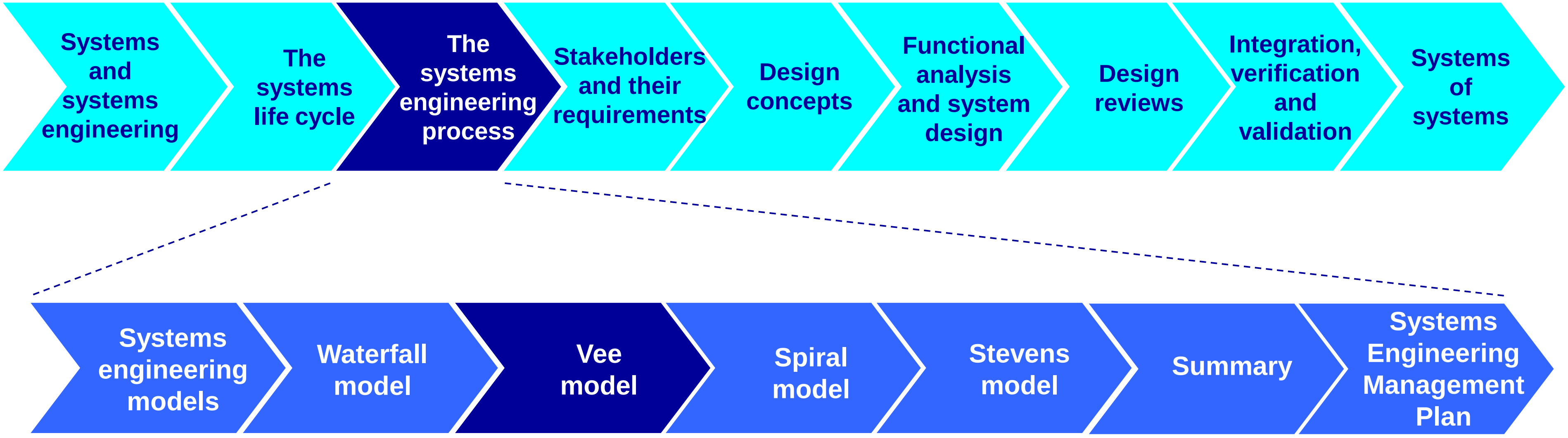
- All requirements must be known upfront
- Deliverables created for each phase are considered frozen – inhibits flexibility
- Can give a false impression of progress
- Does not reflect problem-solving nature of software development – iterations of phases
- Integration is one big bang at the end
- Little opportunity for customer to preview the system (until it may be too late)

When to use the Waterfall Model

- Requirements are very well known
- Product definition is stable
- Technology is understood
- New version of an existing product
- Porting an existing product to a new platform.

The Waterfall model

Advantages	Disadvantages
❖ Time and effort spent upfront saves much more time and effort later. ❖ It is based on a pure top-down approach. ❖ Each phase is validated before next phase is undertaken. ❖ It is easy to understand.	❖ Demands that requirements are frozen initially, preventing learning from prototypes. ❖ The need to accomplish phases sequentially prevents true learning from them. ❖ There is lack of visibility of the entire life-cycle. ❖ Steps in the process are viewed as independent from one another. ❖ Feedback among steps is almost neglected.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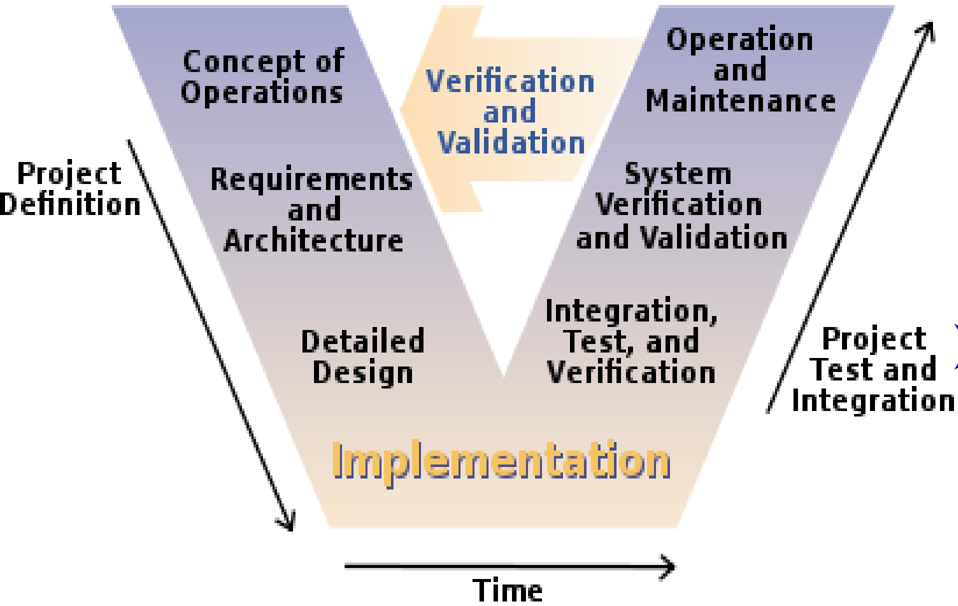
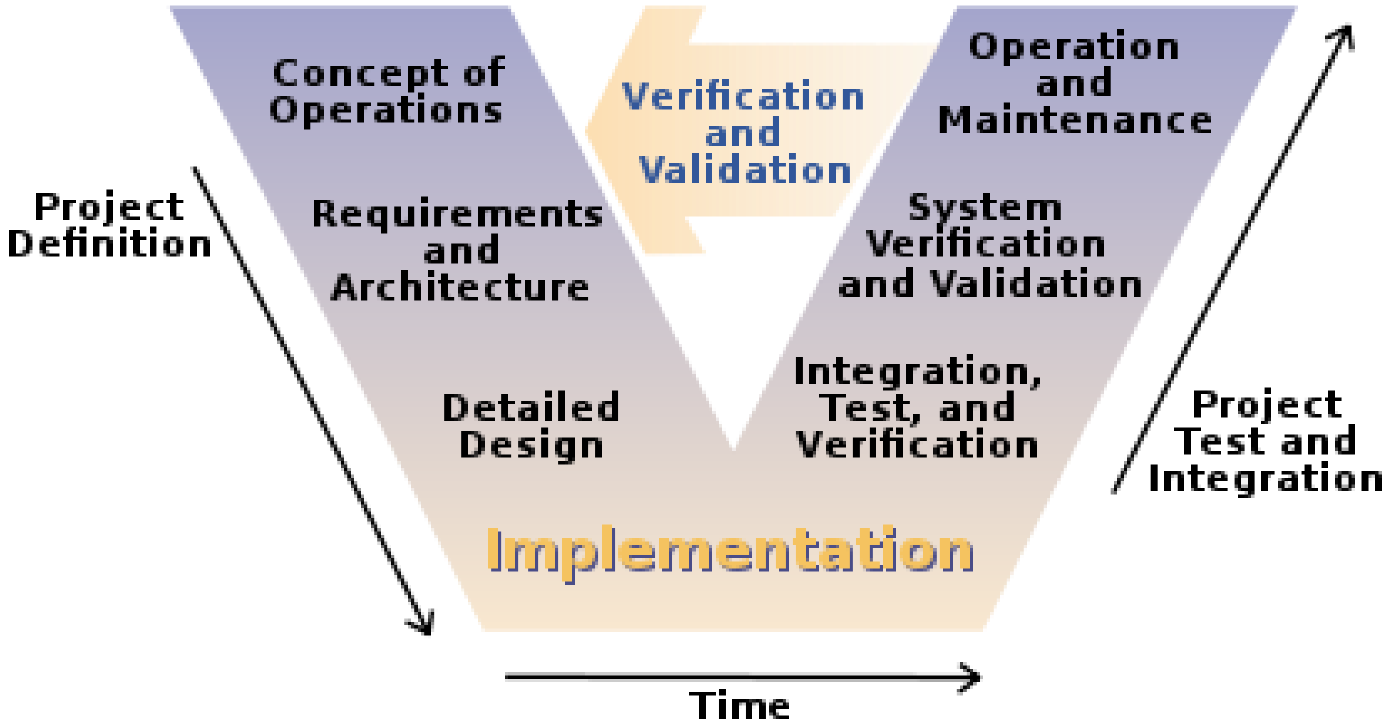
The Vee model



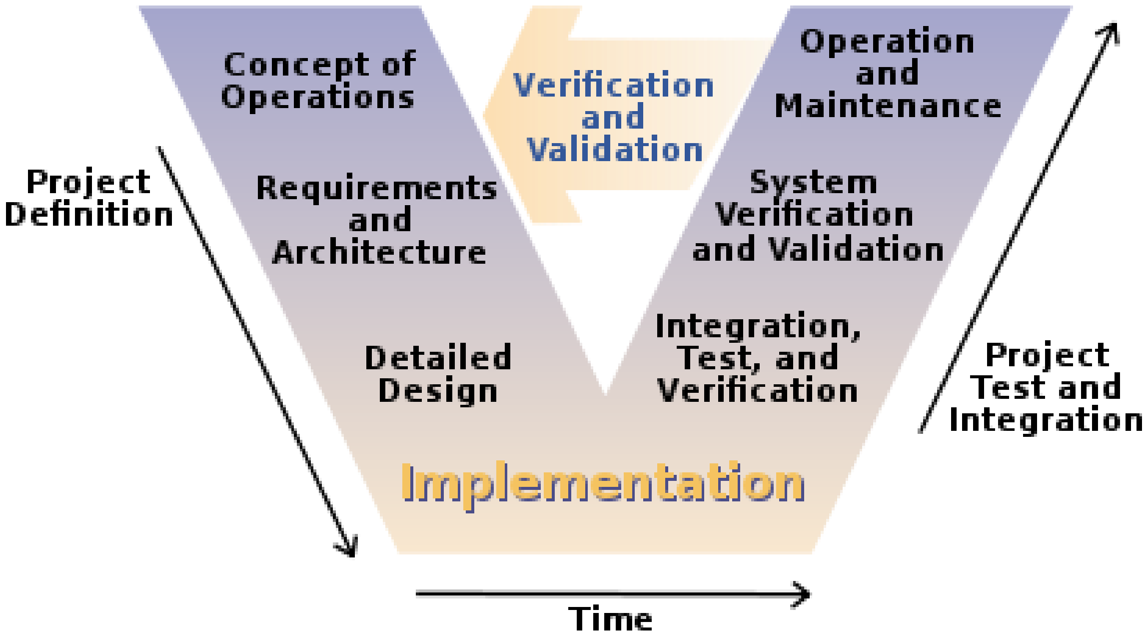
- The Vee model was developed independently in Germany and in the States in the late 80s.
- It reflects both a top-down and a bottom-up approach to system development.
- ‘V’ stands for both Verification and Validation.

The Vee model



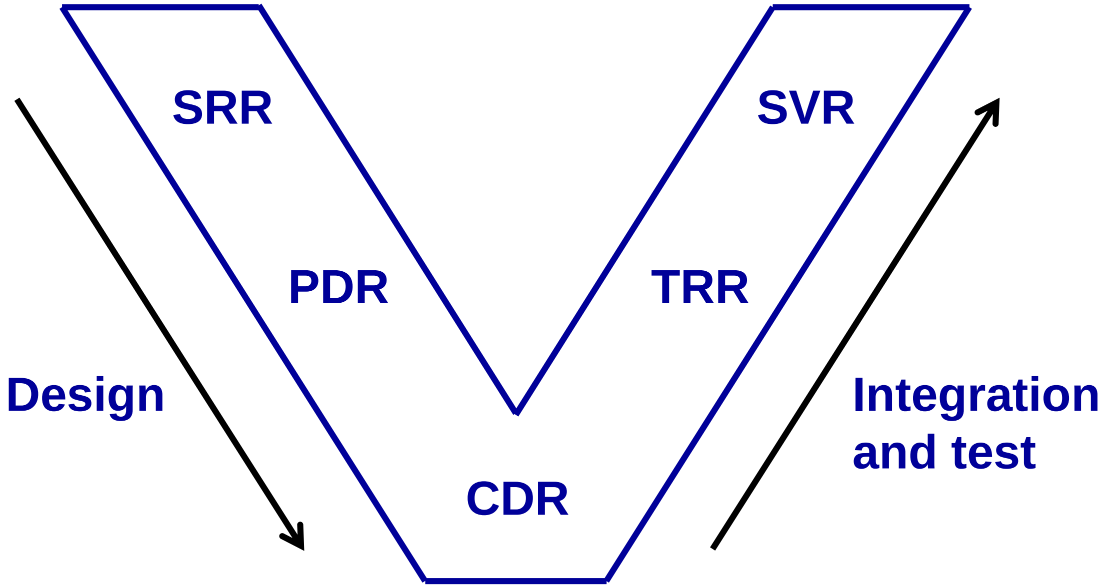
The Vee model has the sequentiality of the relay race, but is much closer to the 'rugby team' approach than the Waterfall model.

The Vee model



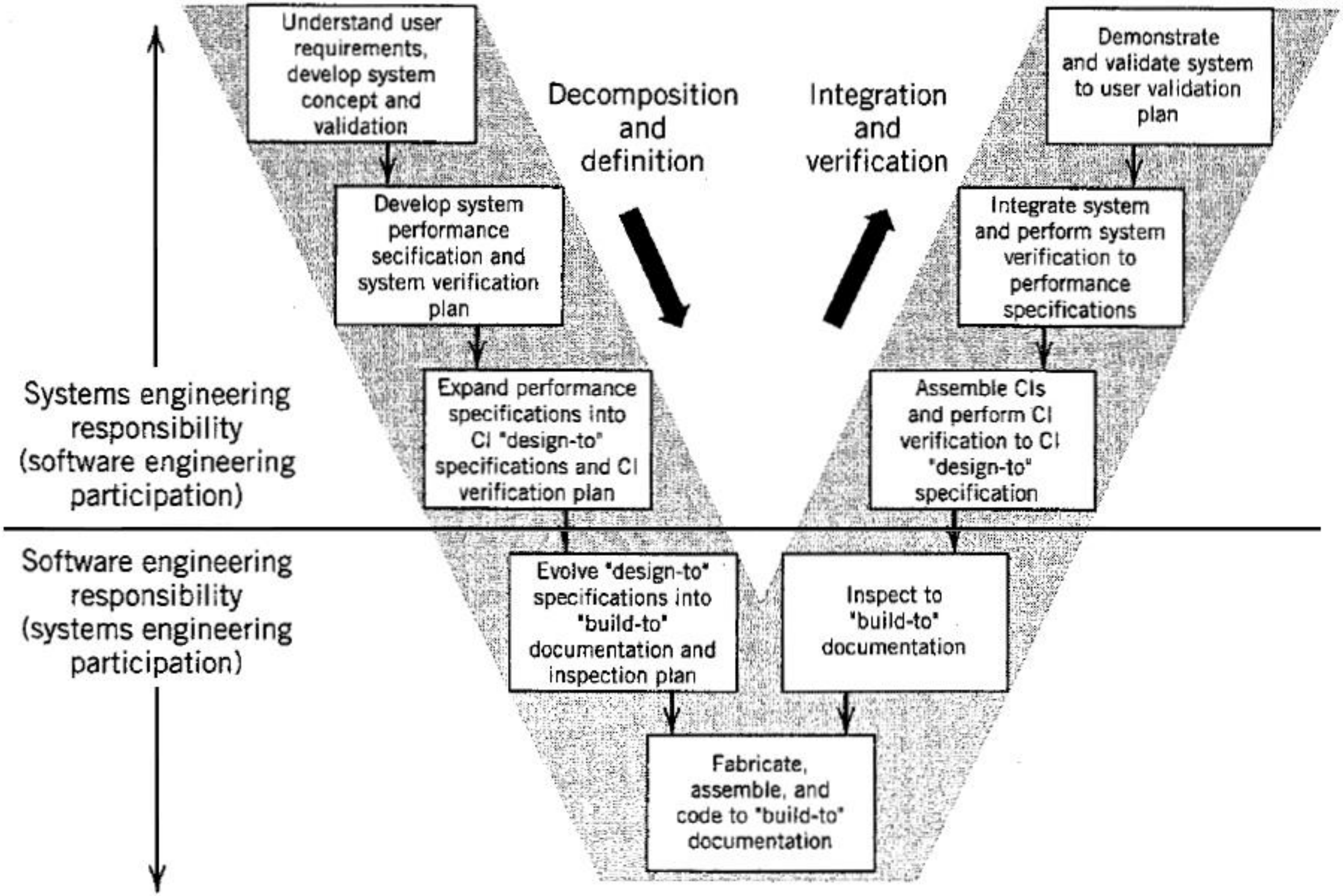
- ➢ The left side of the Vee represents the evolution of the requirements into the preliminary and detailed system design.
- ➢ The right side of the Vee represents the integration and verification of system components through testing.

The Vee model

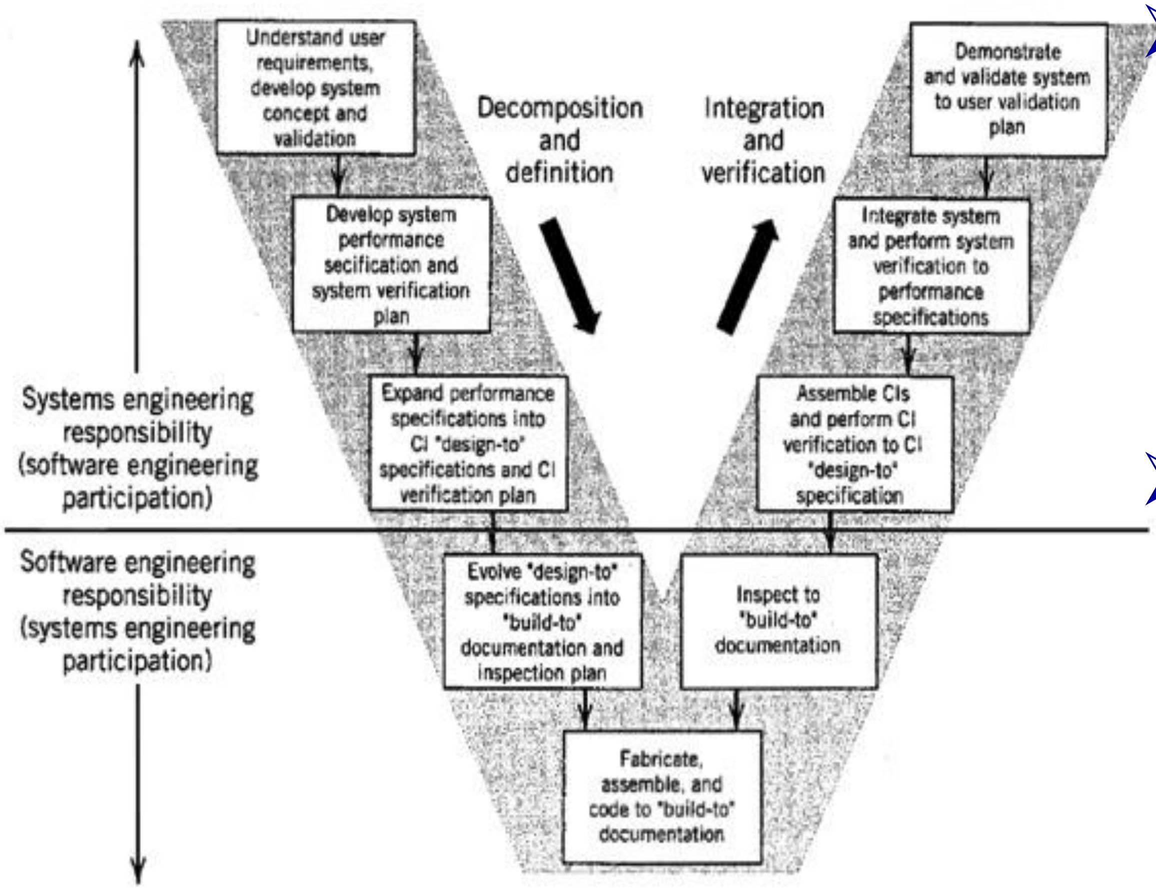


SRR – System Requirements Review
PDR – Preliminary Design Review
CDR – Critical Design Review
TRR – Test Readiness Review
SVR – System Verification Review

The extended Vee model



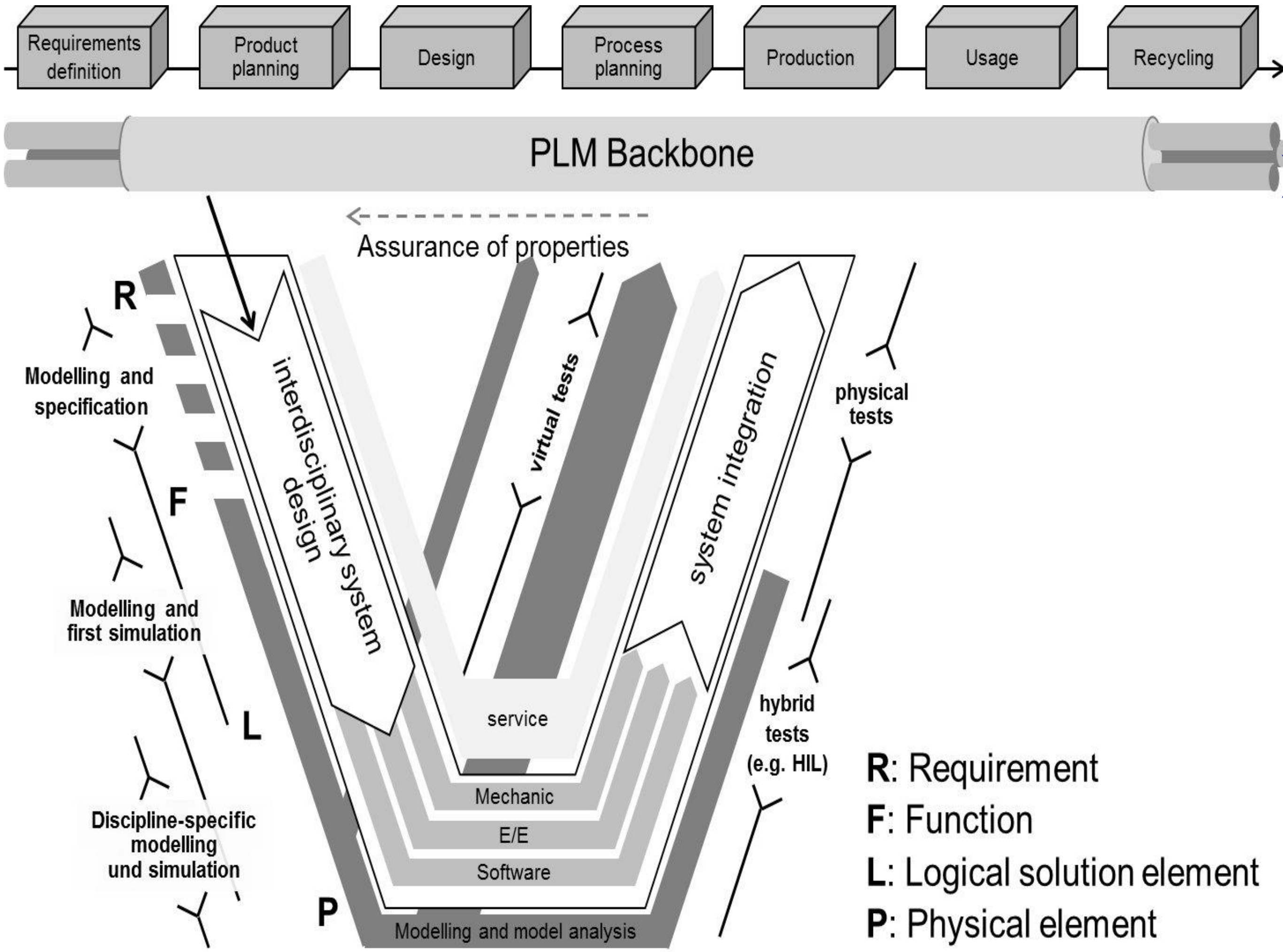
The extended Vee model



- The extended Vee model was proposed by B. G. Downward in 1991.
- It shows the boundary between systems engineering and software engineering.

The extended Vee model

Extended V-model for model based systems engineering

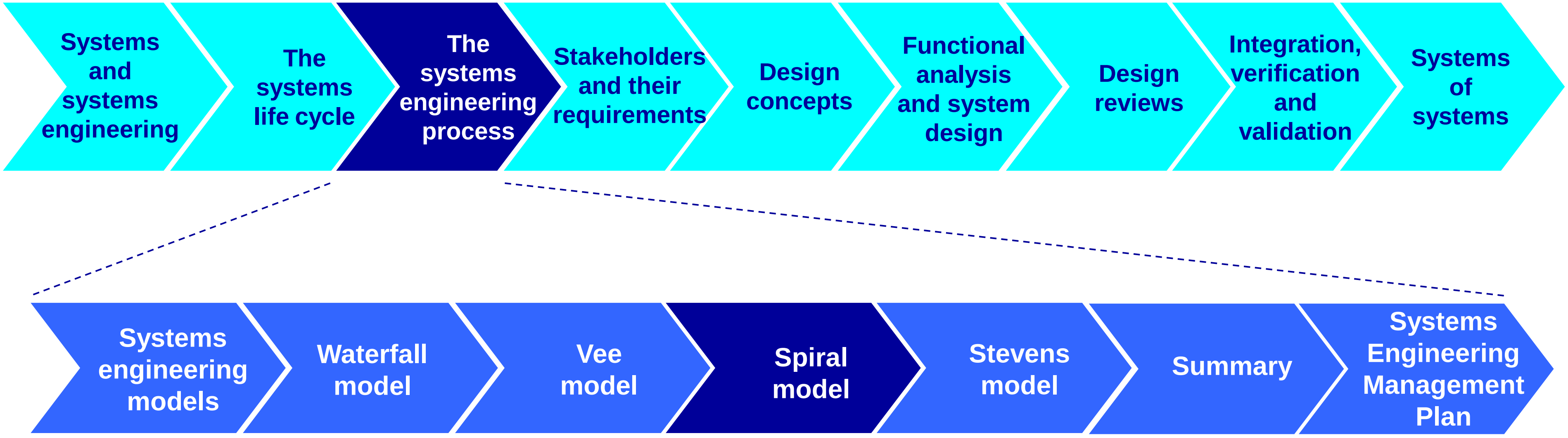


- Extended model-based approach to virtual product development.

http://www.plmportal.org/research-in-detail/items/interdisciplinary-product-development.html

The Vee model

Advantages	Disadvantages
❖ Emphasizes requirements-driven design, testing and integration. ❖ Traceability of requirements is done throughout the entire process.	❖ The life-cycle phases of system use (which includes system maintenance and support) and retirement are not properly addressed by the model.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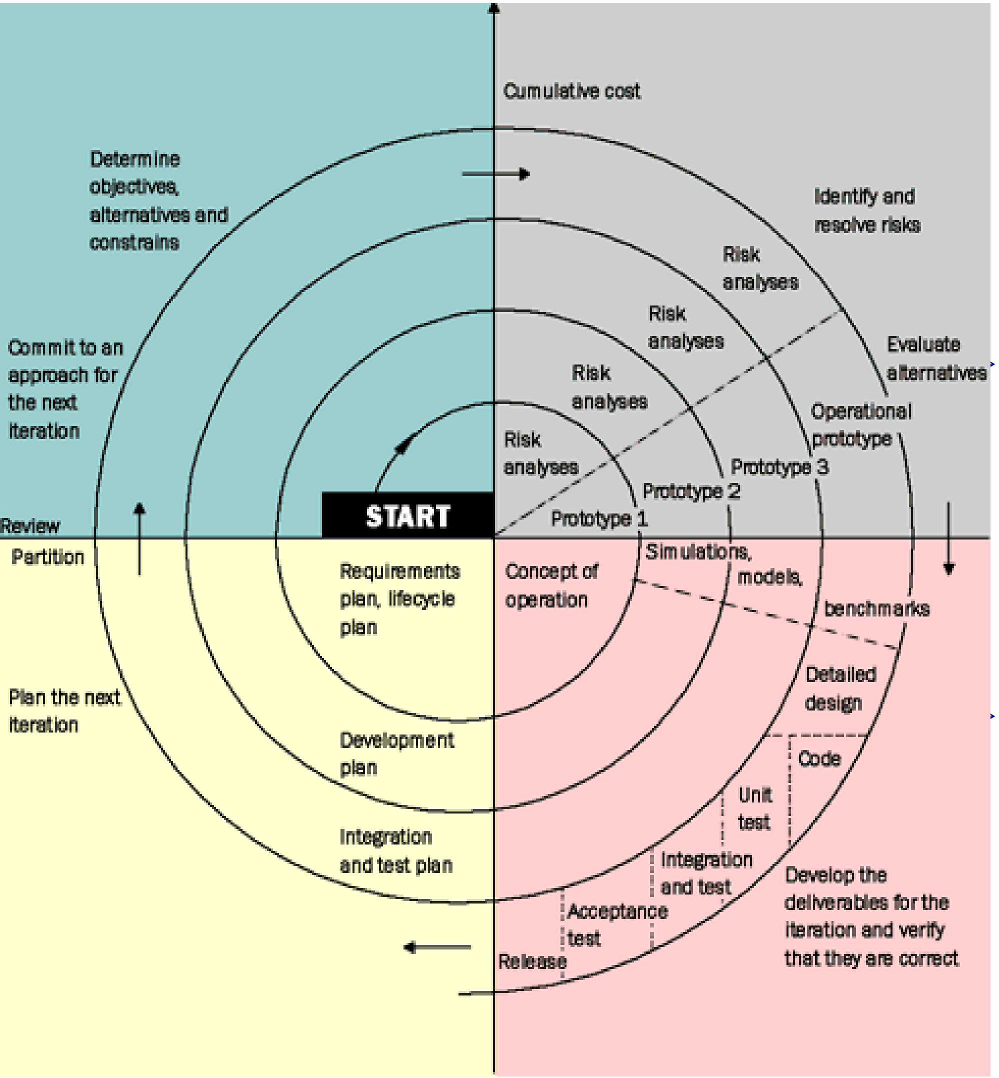
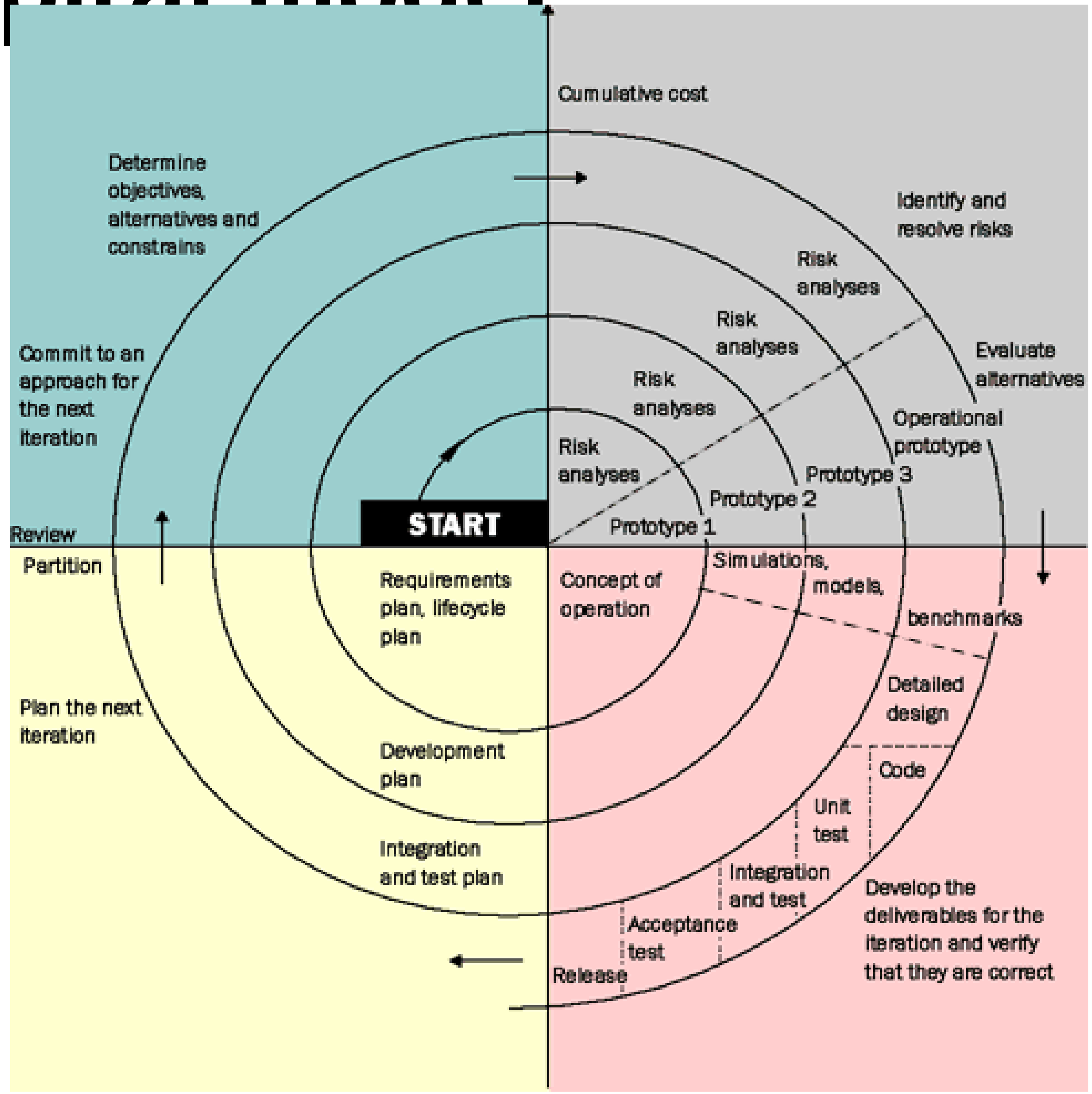
The Spiral model

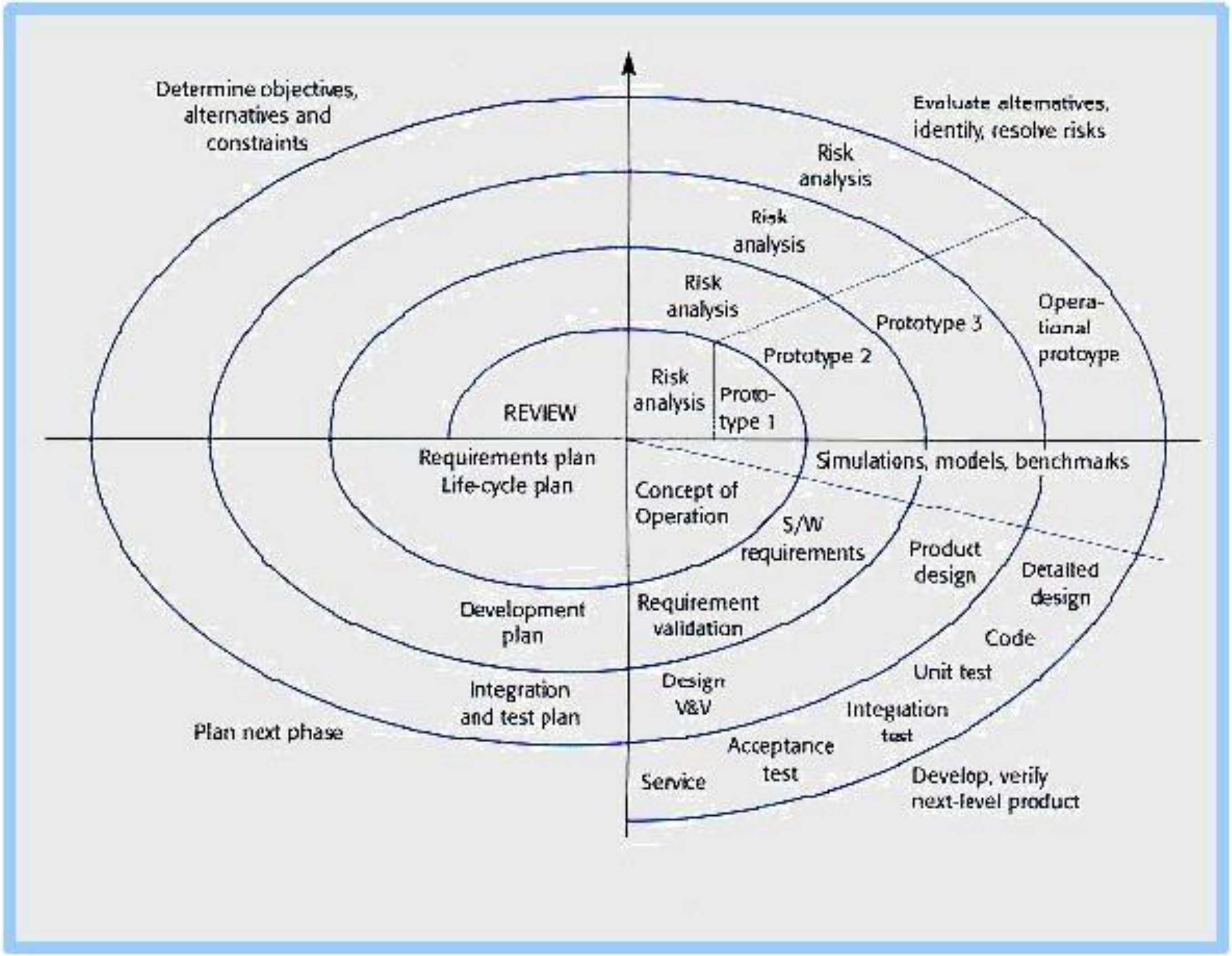


- The Spiral model was developed in 1988 by B. Boehm for software-intensive systems and later refined by A. Sage in 1992.
- Objectives, strategies, risks, design alternatives and validation methods are continuously examined.
- System design and development results through several iterations of the model. The model explained why iteration is so important in the design effort!

The Spiral model

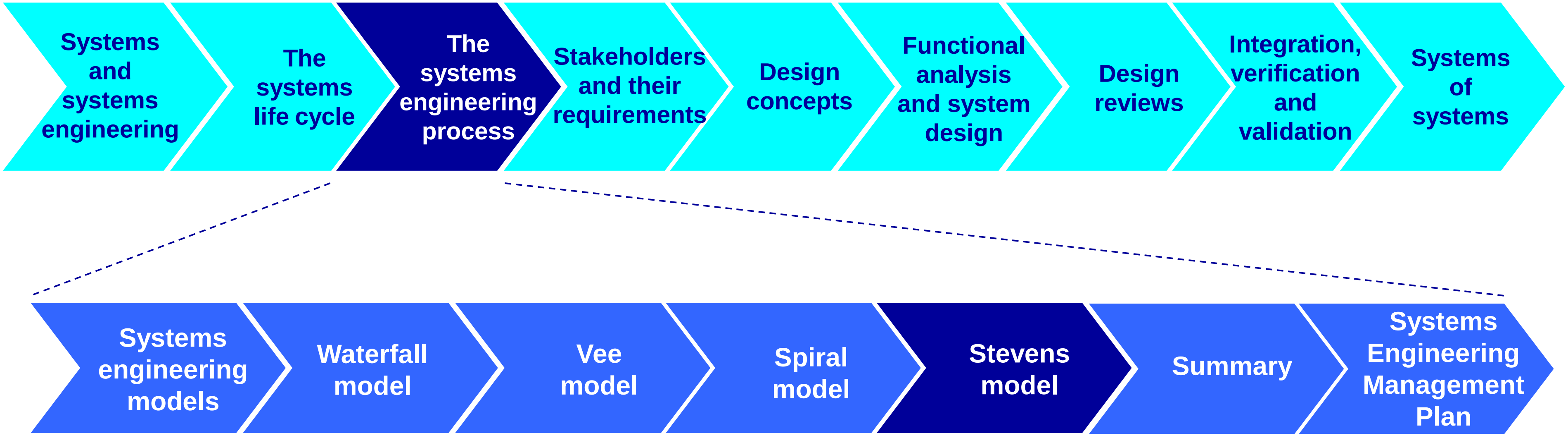


The Spiral model



The Spiral model

Advantages	Disadvantages
❖ Continuous iteration enables the identification and materialization of learnings throughout the process. ❖ It is a balanced combination of sequential activities and parallel thinking.	❖ Emphasis on iteration may lead to less effort in defining things thoroughly upfront. ❖ Excessive iterations may convey longer development times and higher costs.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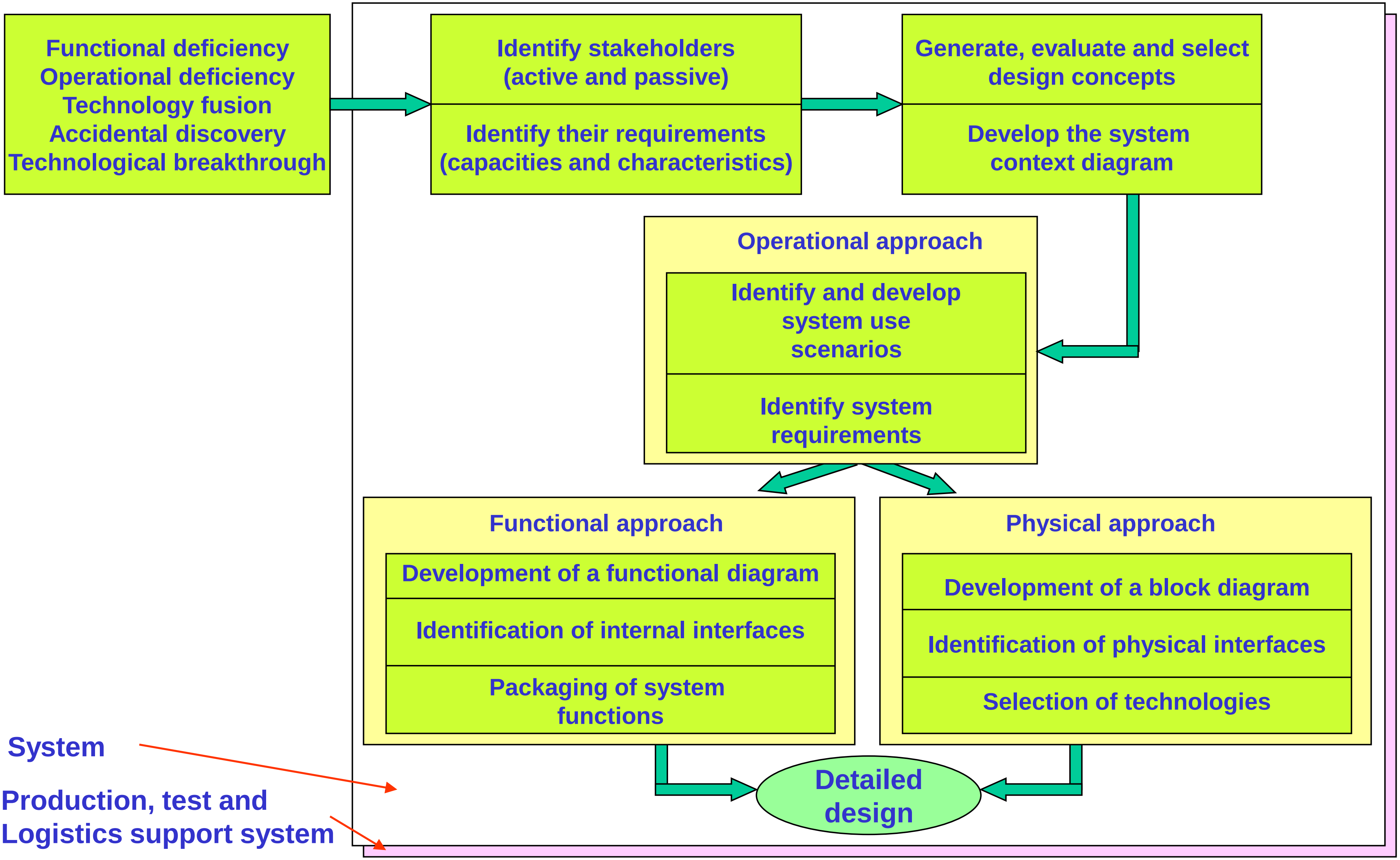
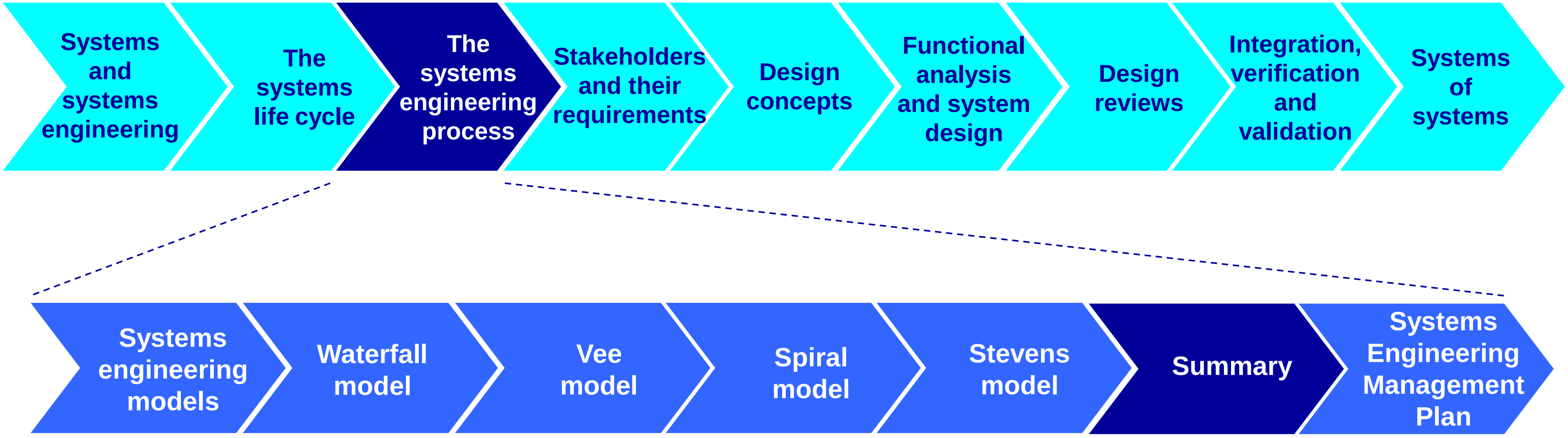
The Stevens model



Software engineering models

Ability to Develop Systems	Structured Methodologies		RAD Methodologies			Agile Methodologies
	Waterfall	Parallel	Phased	Prototyping	Throwaway Prototyping	XP
with Unclear User Requirements	Poor	Poor	Good	Excellent	Excellent	Excellent
with Unfamiliar Technology	Poor	Poor	Good	Poor	Excellent	Poor
that are Complex	Good	Good	Good	Poor	Excellent	Poor
that are Reliable	Good	Good	Good	Poor	Excellent	Good
with a Short Time Schedule	Poor	Good	Excellent	Excellent	Good	Excellent
with Schedule Visibility	Poor	Poor	Excellent	Excellent	Good	Good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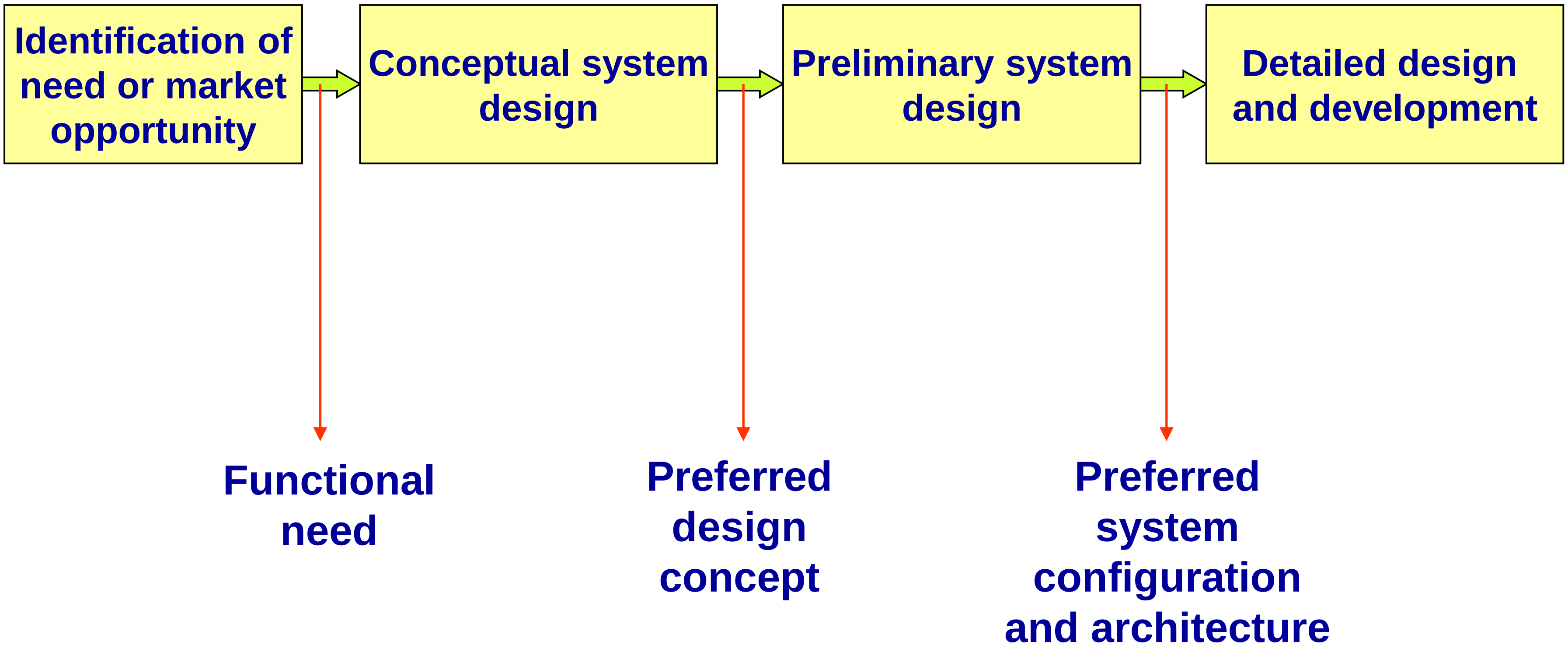
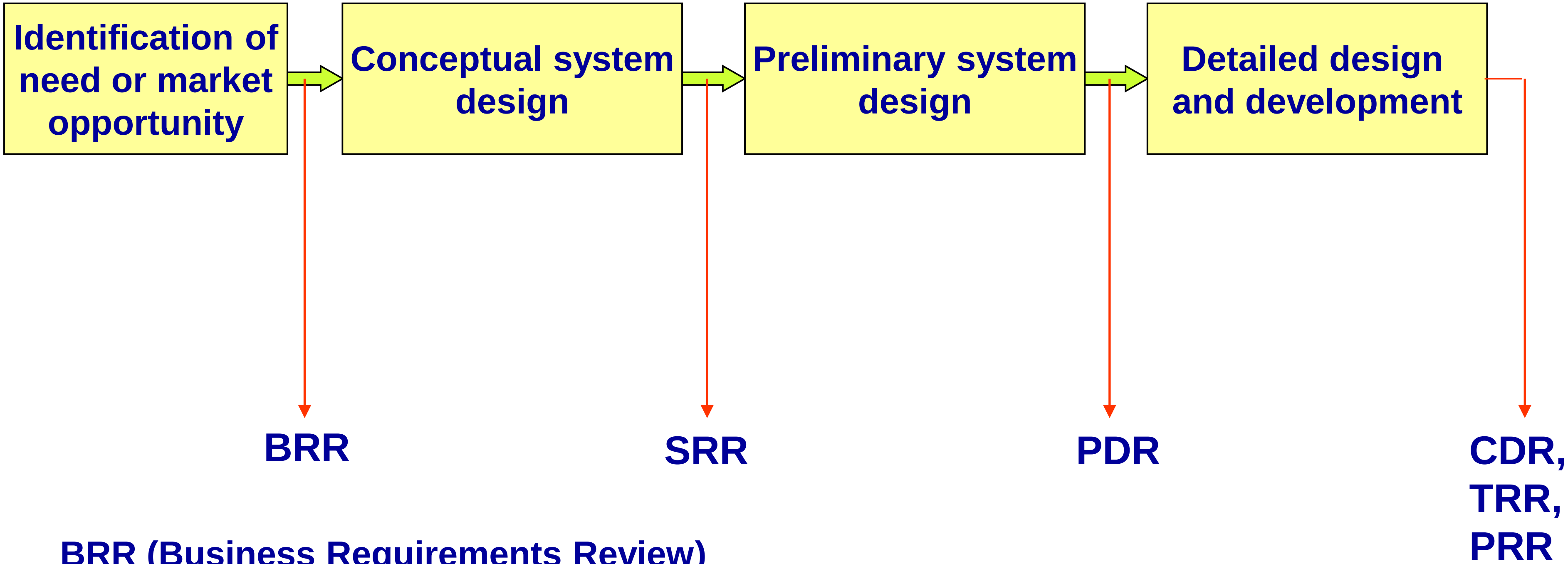
Systems engineering



Systems engineering



BRR (Business Requirements Review)

SRR (System Requirements Review)

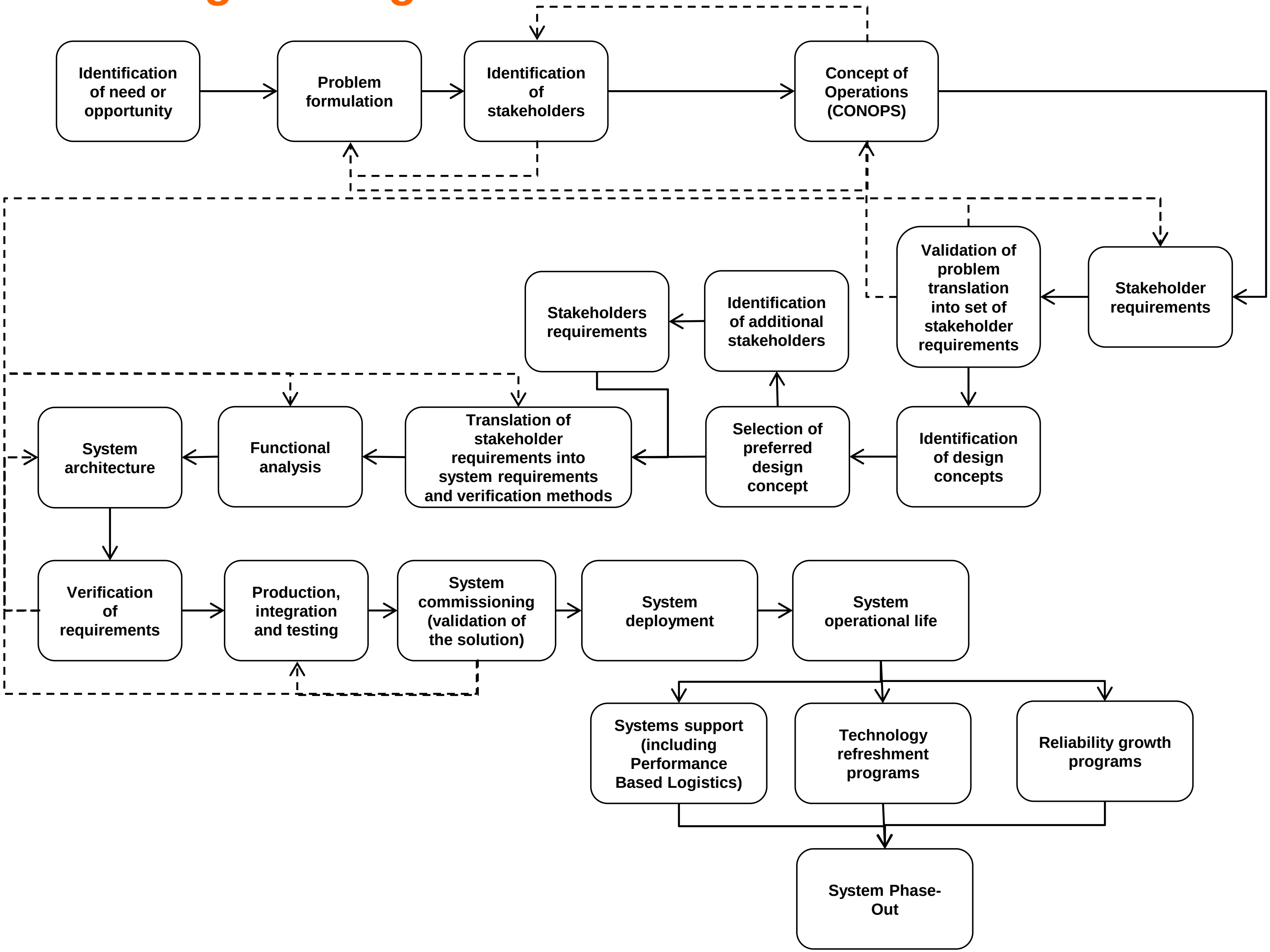
PDR (Preliminary Design Review)

CDR (Critical Design Review)

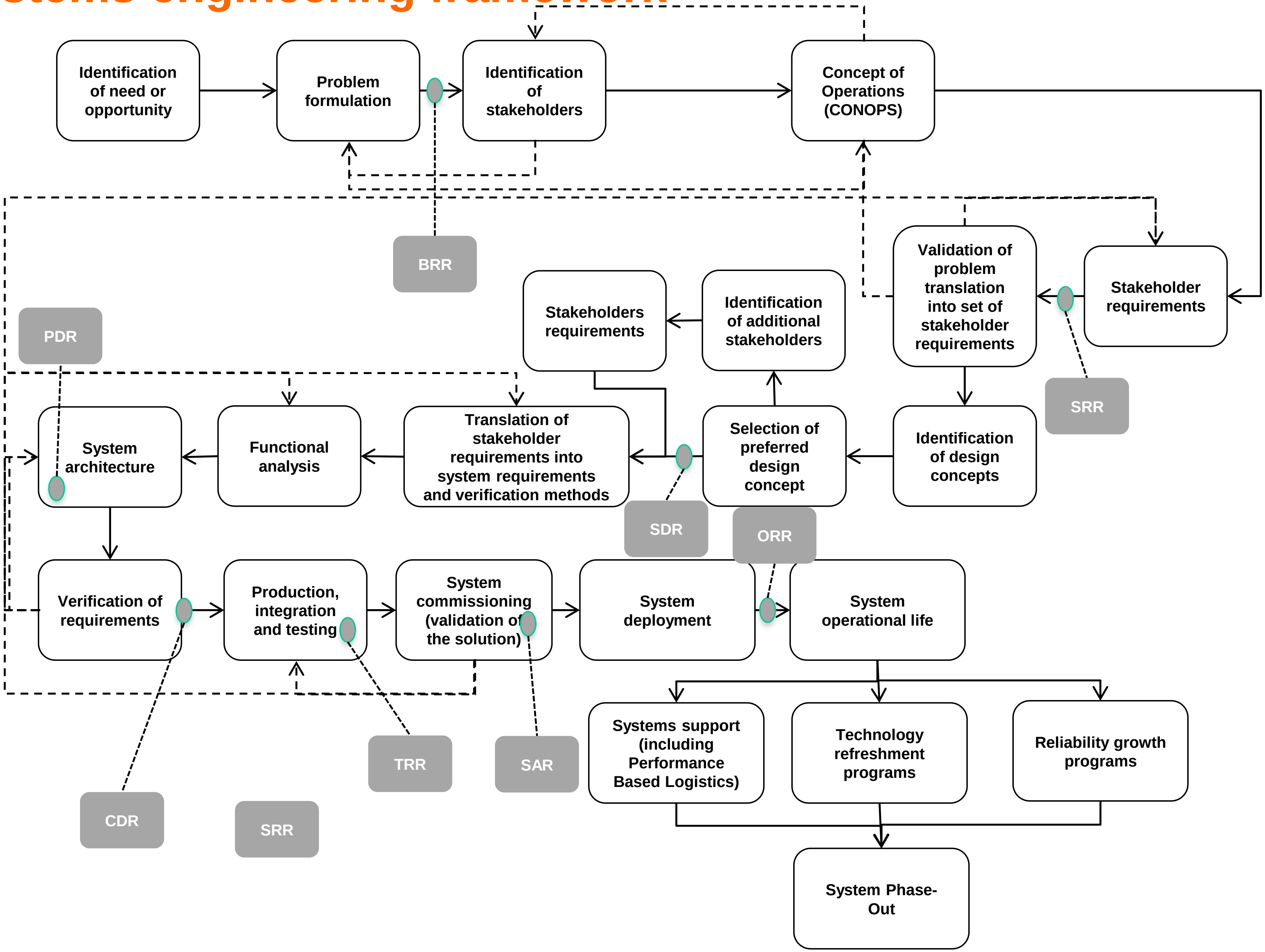
TRR (Test Readiness Review)

PRR (Production Readiness Review)

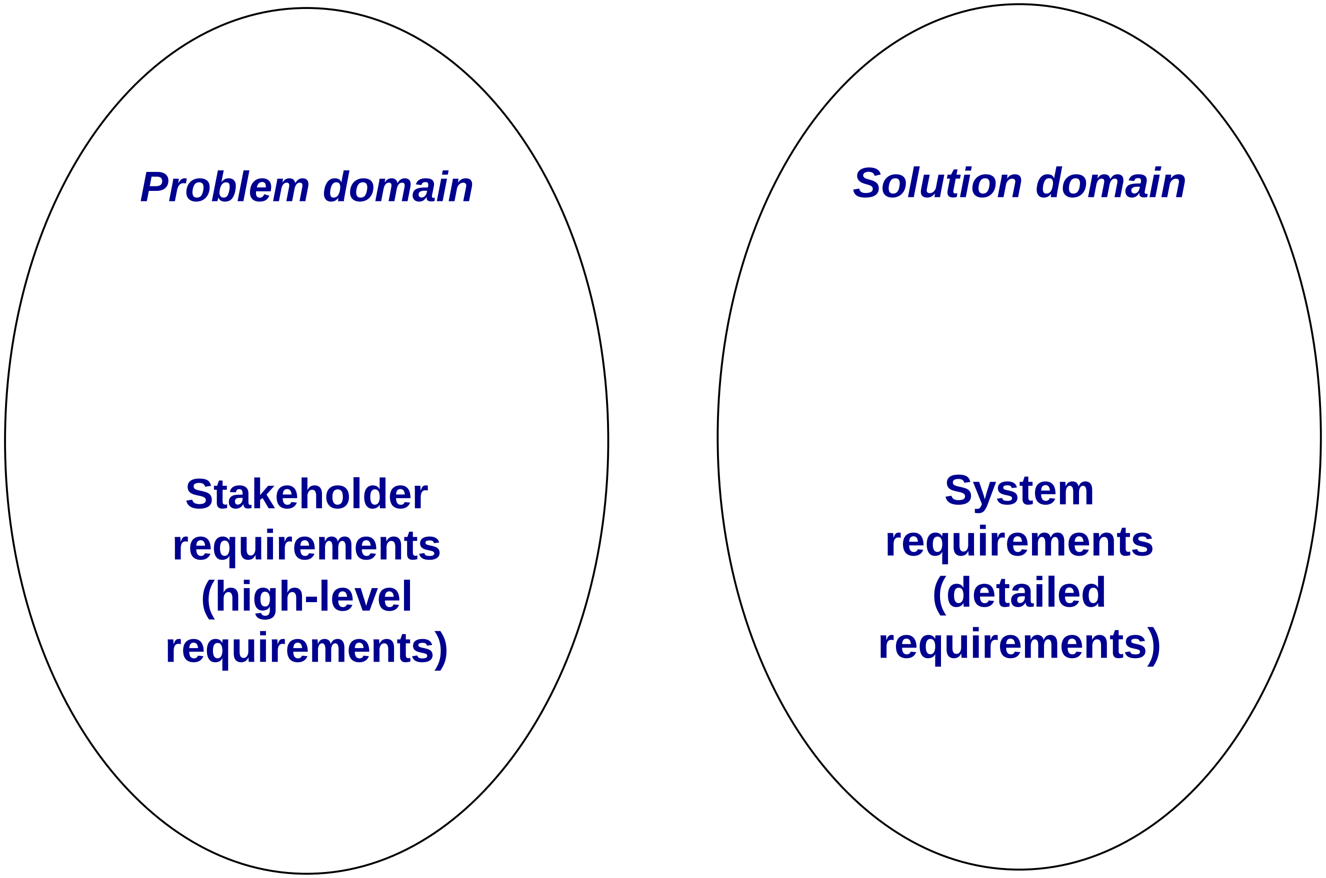
Systems engineering framework



Systems engineering framework



Separation of domains



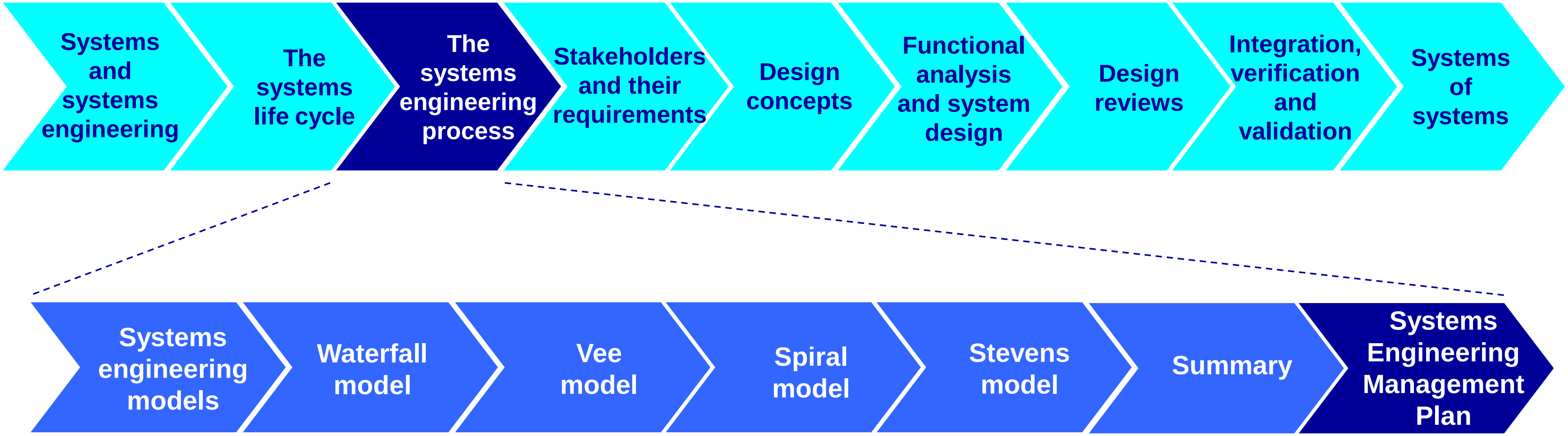
Separation of domains

Two potential origins

Customer stating a need	Perceived market opportunity
✓ The customer identifies the need or opportunity. ✓ The customer has the last word in the formulation of the requirements, as a translation of his identified need or opportunity. ✓ The customer verifies, or demands objective evidence of the verification and fulfillment of the requirements at several stages in the design and development process, including at system delivery. ✓ The customer has to take delivery of the system designed and developed by the contractor if it meets all the formulated requirements. ✓ In case of doubt the contractor can go back to the customer seeking the needed clarifications.	✓ The designer and developer identifies a potential market need or opportunity and formulates the requirements, based on his belief of what the market would demand and accept. ✓ Even if the system meets all the requirements, there is no assurance of its acceptance by the market. ✓ The interested customers purchase the system in the belief that its characteristics and performance are those reflected in its technical specifications, without personally verifying them. ✓ In case of doubt the designer and developer has no one to resort back to when seeking formal and official clarifications.

Summary

- All models can potentially deliver the needed system.
- All models involve some type of iteration.
- The important thing is to truly understand the need or opportunity and maintain at all times the global view.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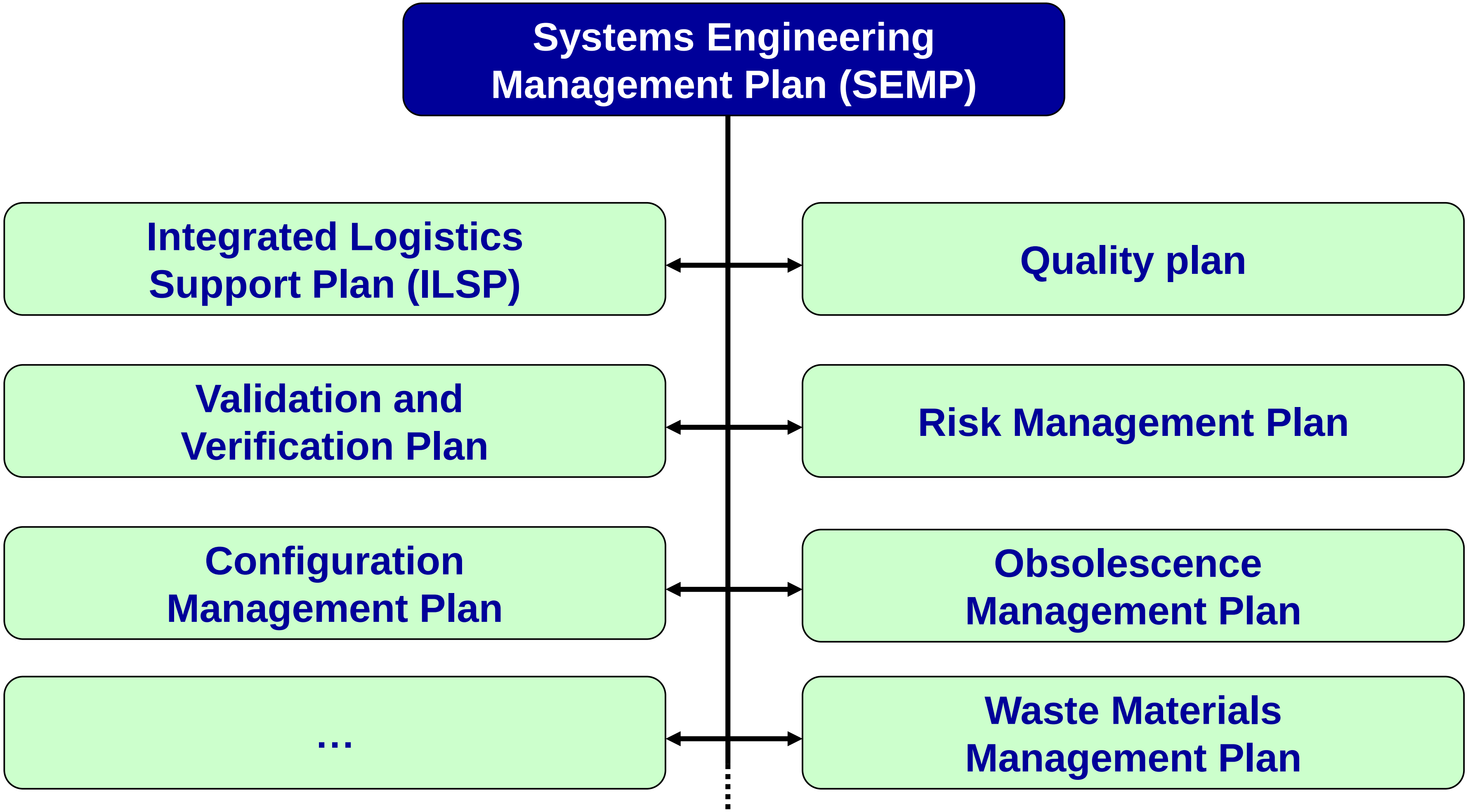
- **The Systems Engineering Management Plan (SEMP) is the document that integrates all the necessary activities and efforts required to achieve the project objectives.**

- **The goal of the SEMP is to make explicit the organization and the management and control mechanisms requierd to achieve the project performance, cost and milestones goals. The SEMP defines what has to be done, who has to do it, when where and how. The SEMP is further developed and complemented by specific plans in the different areas required in the project.**

One important challenge ?

Systems Engineering Management Plan

- Tasks
- Responsibilities
- Resources
- Timescales


Systems Engineering Management Plan (SEMP)
Integrated Logistics Support Plan (ILSP)
Quality plan
Validation and Verification Plan
Risk Management Plan
Configuration Management Plan
Obsolescence Management Plan
…
Waste Materials Management Plan

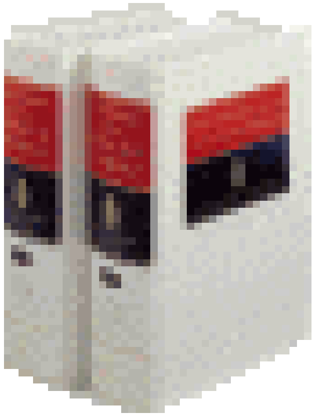
- **It is possible to use different task representation techniques such as Gantt, PERT, CPM, Critical Chain, ...**

- **It is essential that the SEMP defines under a global or holistic view all the necessary activities, efforts, responsibilities and resources required to attain the project goals.**

SEMP checklist

1. Has a SEMP been prepared?
2. Does the SEMP address all activities and all life-cycle phases?
3. Does the SEMP address the adequate integration of all technical disciplines involved in the design and development of the system?
4. Does the SEMP integrate adequately other plans, such as the Integrated Logistics Support Plan, or the Configuration Management Plan, or the Validation and Verification Plan?
5. Have the Work Breakdown Structure, the definition of responsibilities, the timescales, the cost estimates, the follow-up and control mechanisms, and the like, been defined?
6. Have requirements for suppliers been considered?
7. Are formal design reviews contemplated?
8. Has a formal evaluation and corrective action system been implemented?
9. …

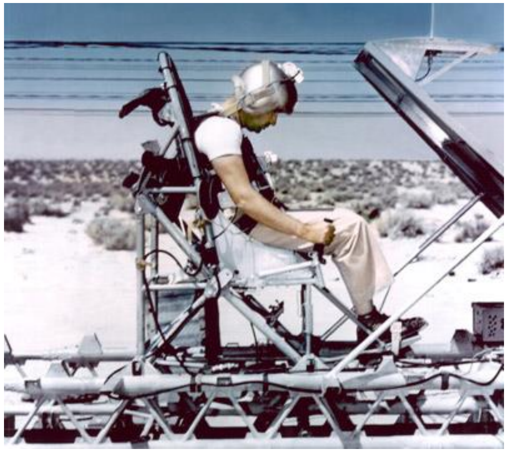
Risk management



- ***Risk*** **(from classic Arab *rizq*, 'what fate may have in store'). Contingency or proximity of a damage.**

- **An essential part of any systems engineering effort is a sound risk management approach.**

Murphy's Law

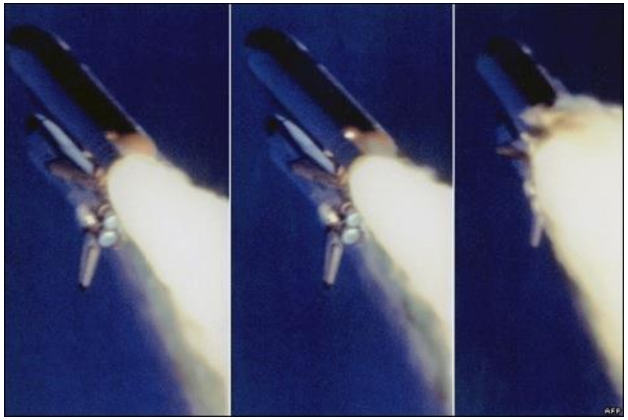


Edwards Air Force Base, 1949. Air Force Project MX981 "Study of the effects of sudden decelerations on the human being"

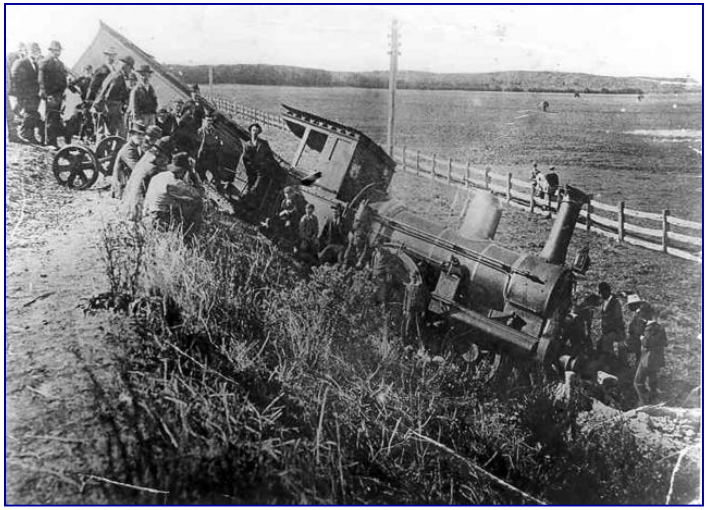
After detecting a wrong connection in a transductor, Capt. Edward A. Murphy said …

'If anything can go wrong, it will'

(Murphy's Law)

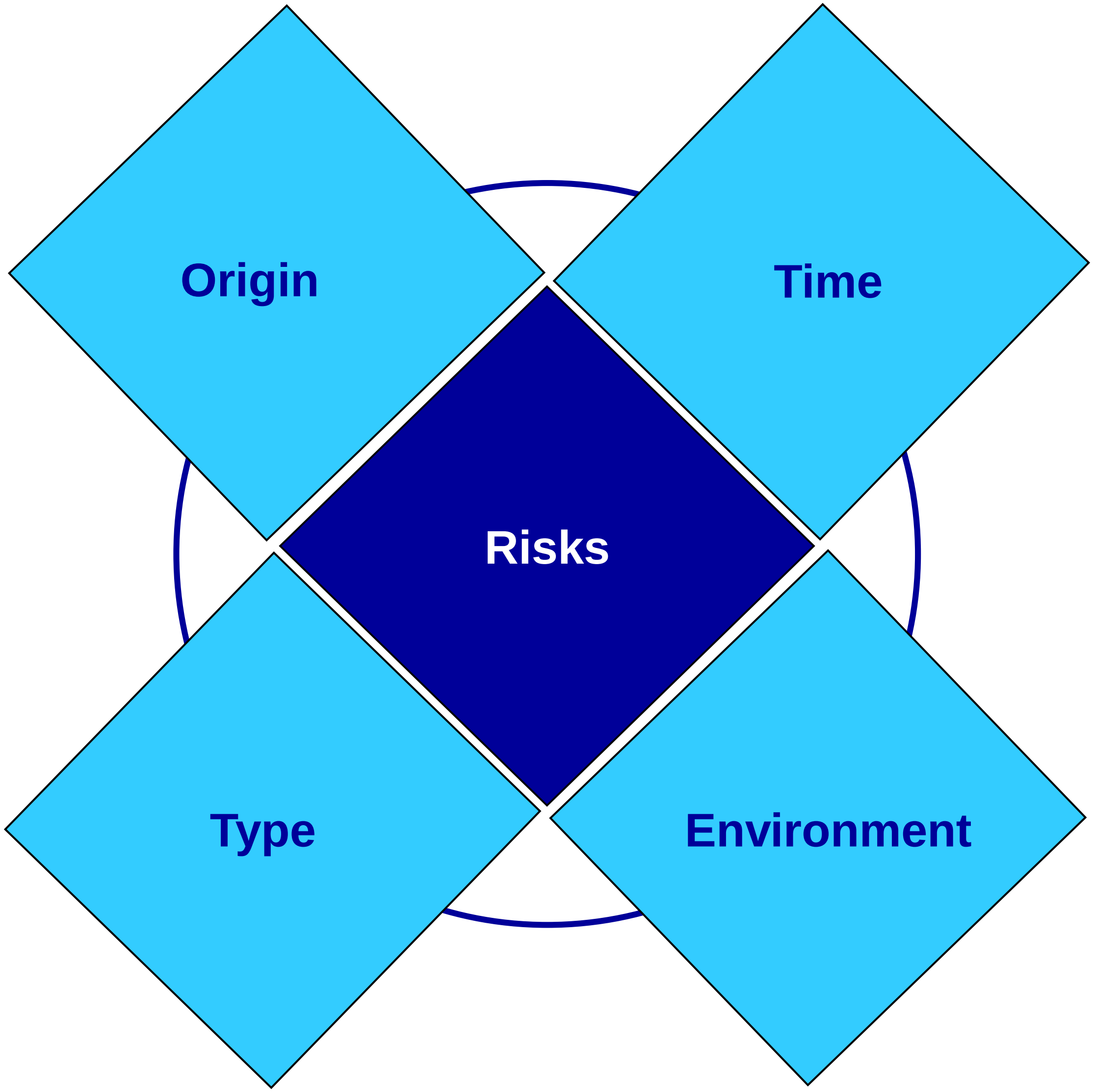


Who has not suffered the failures of systems or equipment?

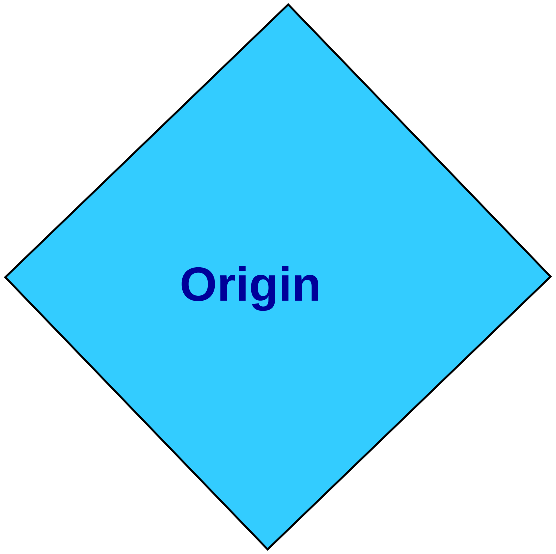


Who has not suffered the failures of systems or equipment?

Facets of risks

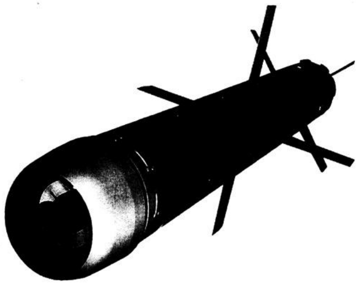


Facets of risks



- **Predictable: risk reasonably well understood and for which likelihood of occurrence and potential consequences can be estimated.**
- **Emergent: risk little known and for which reasonable estimates can not be made.**

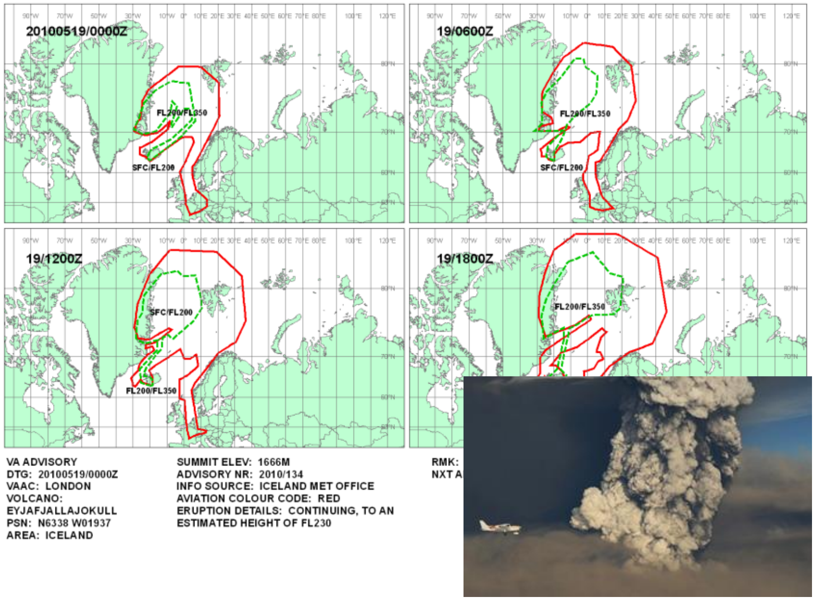
Facets of risks



- What is the risk of a reduction in program scope?

- What is the risk of a delay in the deliveries in the program?

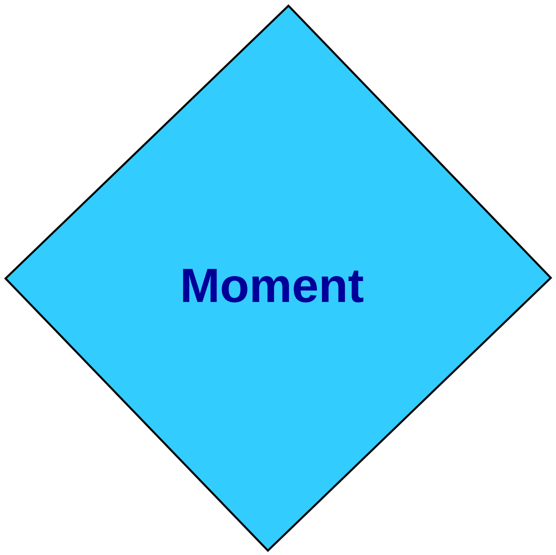
Facets of risks

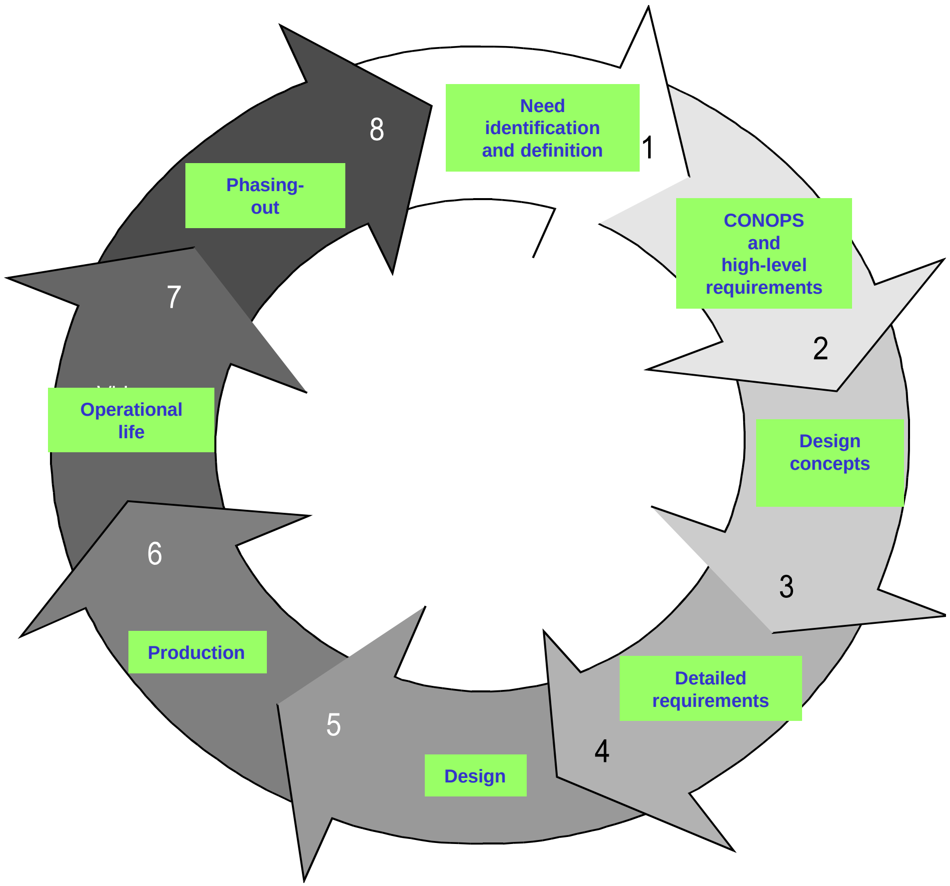


- **Who could have anticipated the ash cloud created by the eruption of a volcano in Iceland, that paralized air traffic in Europe in April 2010?**

- **Who could anticipate in the 80s the risks posed to companies that operated or had presence in the World Wide Web?**

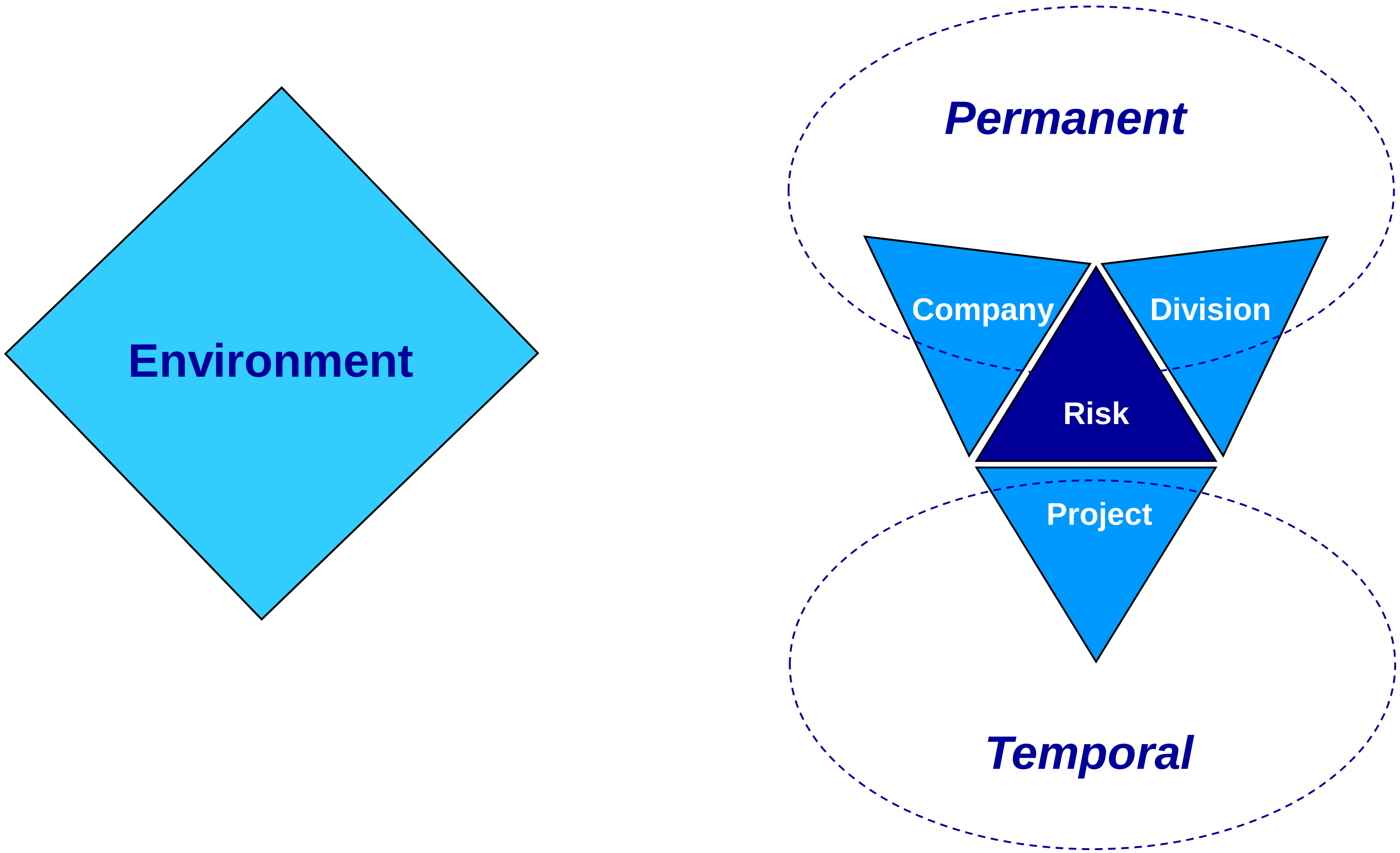
Facets of risks





Risks can materialize in any phase of the life-cycle!

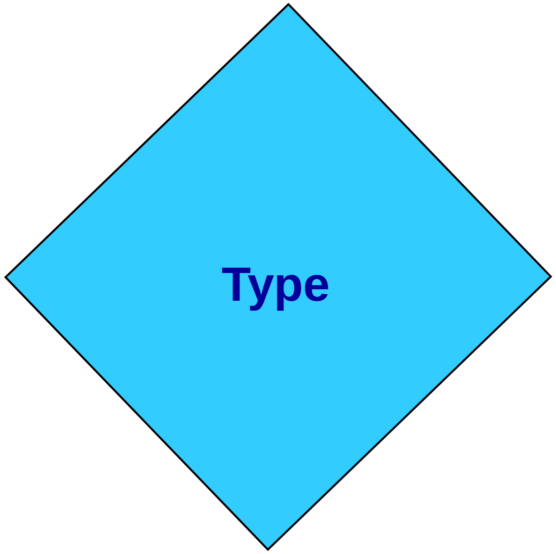
Facets of risks



Facets of risks

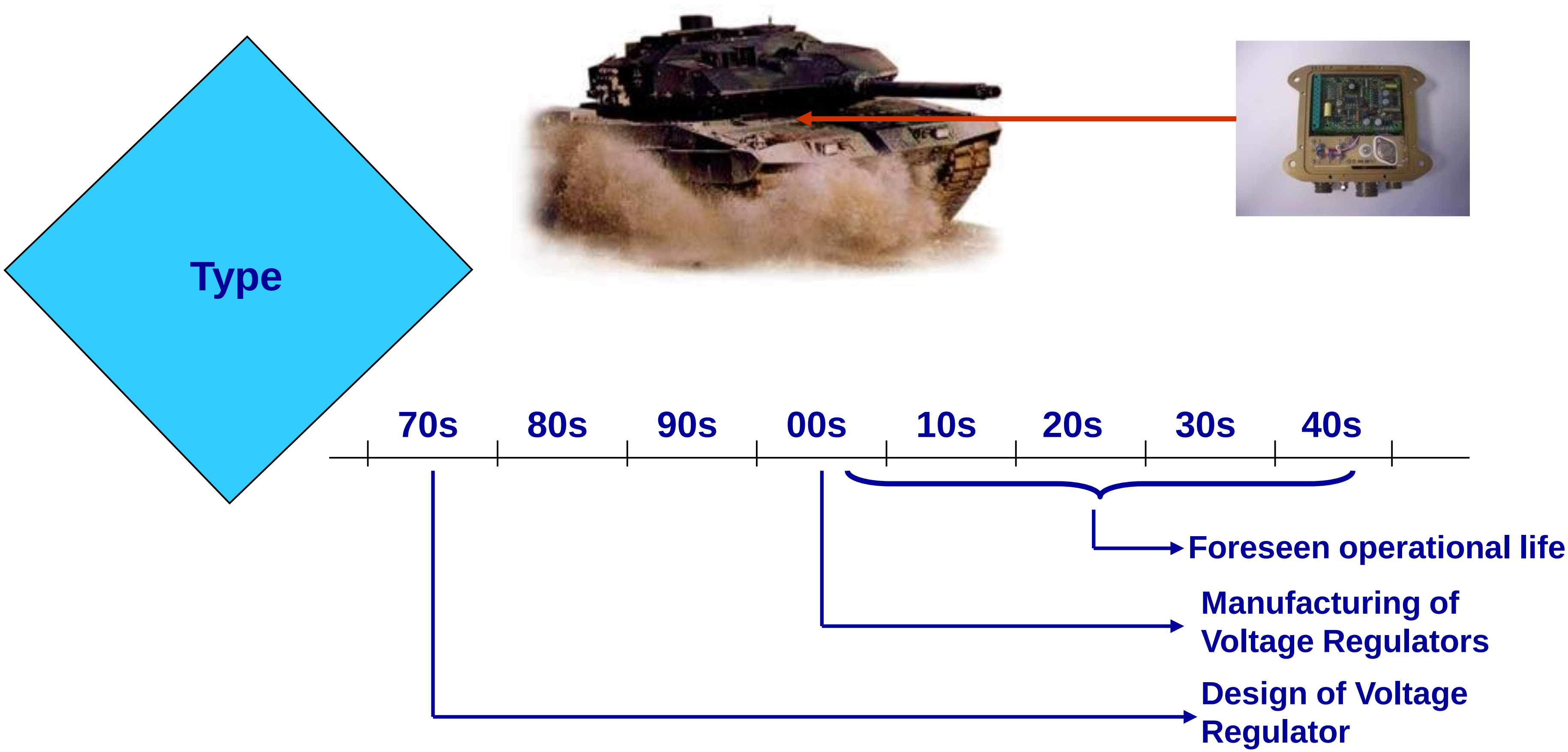
Environment	Risk
Project	• Lack of acceptance by user. • Delay in deliveries from suppliers. • Differences between skills required and skills available in team members. • Technology not available as needed, time- or capabilities-wise. • …
Division	• Lack of generational knowledge transfer. • Derivatives of loss of image in a project. • …
Company	• Change in market conditions. • Emerging projects that compete for company resources. • Legal issues. • …

Facets of risks



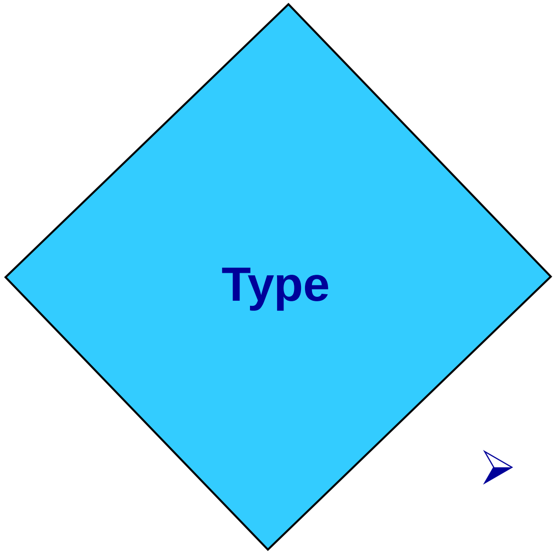
- Human: risks related to people.
- Technical: risks related to system performance and capabilities.
- Economic: financial risks.

Facets of risks



What happens when a design change is requested to something designed many years back?

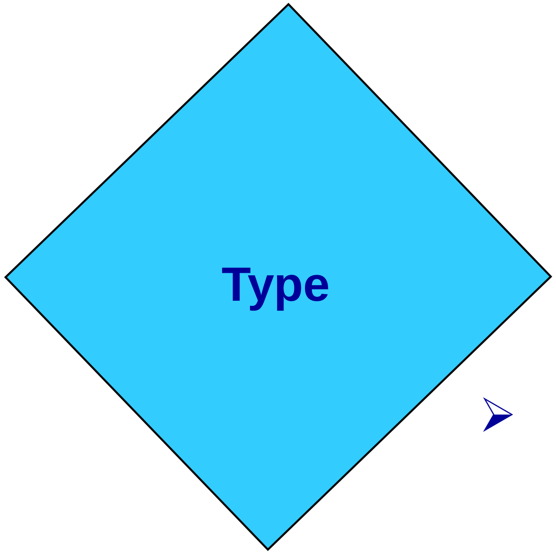
Facets of risks

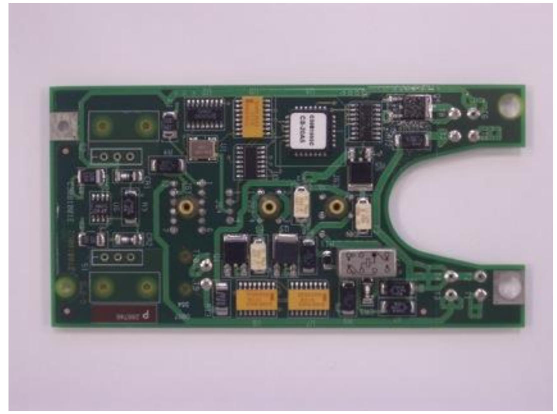


- RENFE’s eries S598 of tilting trains designed and manufactured by CAF.
- There are three large suppliers in Europe of train tilting systems.

What happens when the technical performance of a critical subsystem does not meet its contractual requirements?

Facets of risks

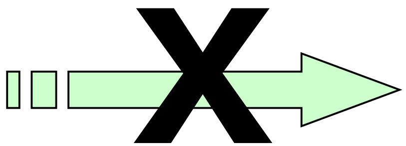




- Electronic board of a missile, manufactured for a Spanish MoD program.
- Manufacturing of the boards represented 20% of company's turnover, materials accounted for 60% of board manufacturing cost and 90% of those materials had to be purchased in US$.

Deliveries of boards to customer spanned over 7 years. What risks were there associated with fluctuations of Euro/US$ exchange rate?

Risk management



Risks are to be identified, assessed, managed and eliminated (or at least mitigated) before they turn into crises!

Risk Management Plan

- The first step is to know what the goal is.
- The second step is to have a plan to get there; but although necessary this plan (SEMP) is not enough .... it is simply a *sine qua non* condition .....
- The third step is to prepare a Risk Management Plan that contemplates what may go wrong, and what can be done (whether proactively or reactively).
- Do we take the appropiate mitigation strategies for the identified risks?

Risk assessment

Likelihood	Consequences				
	Insignificant *(Minor problem easily handled by normal day to day processes)*	**Minor** *(Some disruption possible, e.g. damage equal to $500k)*	**Moderate** *(Significant time/resources required, e.g. damage equal to $1million)*	**Major** *(Operations severely damaged, e.g. damage equal to $10 million)*	**Catastrophic** *(Business survival is at risk damage equal to $25 Million)*
Almost certain *(e.g. >90% chance)*	High	High	Extreme	Extreme	Extreme
Likely *(e.g. between 50% and 90% chance)*	Moderate	High	High	Extreme	Extreme
Moderate *(e.g. between 10% and 50% chance)*	Low	Moderate	High	Extreme	Extreme
Unlikely *(e.g. between 3% and 10% chance)*	Low	Low	Moderate	High	Extreme
Rare *(e.g. <3% chance)*	Low	Low	Moderate	High	High

- ♦ **There are many ways of assessing the identified risks: Defense Systems Management College, MIL-STD 882, BS 8800, ISO 31010:2009, Ishikawa diagrams, …**
- ♦ **Above the more or less rigorous mathematical treatment of each method, all of them entail a large degree of subjectivity: the assessment of he who does the analysis of the likelihood of occurrence and the severity of the eventual consequences.**

Risk mitigation strategies